Strategic Reusability Planning and Management in Product Development

by

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Ingénieur, Ecole Centrale Paris (1996)

Submitted to the Department of Mechanical Engineering in partial fulfillment of the requirements for the degree of

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Competitive Product Development

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Abstract

Reusability consists of the ability to reuse existing, analogous or competitive design concepts, parts, systems, facilities and tooling. Reusability is a strategic enabler in supporting breakthrough efforts for achieving affordable customer-perceived product variety, and product freshness along with design and manufacturing cost reduction, development time reduction, and quality improvement. The present study describes a set of strategic management and planning tools to support long term technology, product and process development; to enhance business and engineering efficiency through reusability; and to build market-driven as well as cost-driven products. The tools, integrated into the strategic reusability planning and management process, will help product development teams to focus their development resources on the features that are the most valuable to the customer, and achieve the best balance between reuse and innovation.

Thesis Supervisor: Don P. Clausing
Title: Senior Lecturer
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Chapter I - Introduction

The objective of this research is to create the strategic reusability planning and management process for implementing systematic and optimal reuse when developing families of products, as well as single products. This integrates Quality Function Deployment (QFD), the business integration model, the reusability matrix, and the product planning matrix to create a process that will achieve affordable customer-perceived product variety and new product revenue, while reducing engineering, facilities and tooling costs. This process proposes a methodology leading to the effective utilization of existing assets to achieve the best balance between reuse and innovation.

Simple reuse - piece parts used in more than one product - has long been recognized and partially implemented in the product development arena. This research builds on that simple concept to reuse other assets - including equipment and tooling - in the development of new product programs. This will reduce development and production costs, the development time, while balancing this with the strategic voice of the customer, to achieve customer satisfaction.

An example of product reuse beyond the piece-part level is the reuse of the robust design of a critical subsystem. Even if many of the piece parts are changed, effective planning can reuse the robust critical parameters of the packaging so that the robustness work does not have to be repeated. An example of facilities and tooling reuse is the reuse of existing manufacturing equipment and tooling in the development of a future generational product, by defining hardpoints or constraints for the design engineers so that they design for manufacturability.
The planning process created concentrates new development effort on those areas that have the greatest impact on customer satisfaction, driving design, facilities and tooling changes by customer wants. Any system design that is not directly affected by the new customer wants is systematically targeted for reuse.

1-Background

Reusability analysis was proposed as a means to achieve flexible product development and affordable customer-perceived variety [Clausing 1991] through the application of a reusability matrix. That concept was expanded within the framework of total quality development [Clausing 1994]. Research on the tactical planning and management of reusability to implement reuse within a product development program has been completed [Witter et al, 1994]. It integrates the reusability matrix with the House of Quality (QFD) to integrate reusability with customer satisfaction - for one product. Clausing and Cohen [1994] reported a strategic House of Quality that covers many products within one industry. Collaboration between MIT and Ford in 1994 led to the further development of the business integration model (BIM), which had originally been introduced in [Witter et al, 1994]. Related work in this area deals with the relationship of product architecture and the performance of the firm [Ulrich 1992; Henderson and Clark 1990], product variety [Suzue and Kohdate 1990; Sanderson and Uzumeri 1992; Whitney 1993], and platform planning [McGrath 1995].

By integrating the strategic House of Quality (for many products), the BIM, platform planning and Witter’s process, the basic approach for the strategic planning and management of reusability was created. This embryonic process was then further developed in a joint effort between Ford and MIT.

2- Thesis outline

The thesis is organized into 8 chapters. Before defining the strategic reusability planning and management process, we had to improve and further enhance the existing reusability planning and management tools; and complete the existing set of tools introducing new concepts which better support the planning and quantification of reusability. The thesis is organized in accordance with this approach. After the introductory chapter, the second chapter defines reusability, and the drivers of the reusability decision-making process. The third chapter introduces the Business Integration Model as a planning tool to support product, process, and technology planning; and enhance business and engineering efficiency through reusability. Chapter 4
is an overview and introduction to one possible approach to assess the design, facilities and tooling changes required by new product expectations on the existing products. Chapter 5 outlines a process for achieving a degree of product change that is clearly visible, suitable to the customer, and avoids unnecessary investment. Then Chapter 6 describes one possible approach to assessing the economic value of a product program. Finally Chapter 7 describes the proposed strategic reusability planning and management process for reducing investment costs and development time, for improving quality, but also for effectively using the company’s resources.
Chapter II - Reusability: definition, drivers

1-Definition

The concept of reuse consists of the ability to reuse existing, analogous, or competitive design/process concepts, parts, systems, tooling, and facilities leveraged and supported by innovation in the development of freshening actions, new products, product lines, or platforms.

Reusability is the forward thinking process of structuring product families such that more reuse can be planned for. Reusability is a strategic enabler in supporting breakthrough efforts for effective utilization of existing assets, design and manufacturing cost reduction, development time reduction, quality improvement, and customer-perceived variety achievement.

2- Variants

We will make a clear distinction in this thesis between two different types of reusability: commonality, and carryover.

Commonality focuses on product components, systems, features, product expectations, facilities and tools that are shared with other products, but not the prior model product. Commonality can be compared across models, derivatives (same platform, but different body shell and overhangs for a vehicle for instance), and platforms. Sharing parts, systems will generally reduce the number of new tools and facilities required. Through standardization, commonality can eliminate time and energy wastes in solving the same problem twice. The point of commonality is to set up a standard for all members of a given product range, which makes both material and
processing costs lower. Required capacity protection becomes also lower as volumes are aggregated.

Carryover systems or components focuses on elements reused from prior models. This will enable the reuse of facilities and tooling, which will sensitively reduce the investment costs. As mentioned before, items that have little or no affect on customer perceived value, should be targeted for carryover assumptions.

Product development teams should focus on reusing facilities and tools from prior models. For components’ tools, this could include reusing dies, molds and check fixtures. For component facilities, this could include reuse of presses, injection molding equipment, ovens, machine tools and floor space. For assemblies, reusability could include equipment such as conveyors, workstations, transfer equipment, floor space, and bonding equipment such as welding equipment.

Reusability of facilities and tooling minimizes investment by making use of tools and facilities that are already in place. When capacity is not available, savings in tool design and processing time can still be achieved through reuse of same type of equipment although new.

3- Reusability drivers

One can face some dilemmas when the time comes to decide upon which part, system, or facility to reuse when several options are available. The decision-making process should be based on the evaluation of a certain number of parameters. There follows a list of possible drivers for the reusability decision-making process. This list is far from being exhaustive, and should be carefully reviewed and adapted to the context in which reusability is done. Some of drivers of the decision-making process of parts and systems reusability would be:

- Fixed and variable costs (traditional accounting misleading)
- Performance and Capability
  - Behavior, and interface with other parts
  - Manufacturability
  - Modularity (How flexible is the design?)
- Customer acceptance and satisfaction
- Underlying technology competitiveness
- Capacity availability
- Cost of incremental capacity
- Reuse Effectiveness for the asset X considered:

\[ \omega = \left[ \frac{\sum_{i=1}^{n} (C_i^N - C_i^R)}{C_i^D} \right] \times \left[ \frac{T}{\Delta t} \right] \]

Where:

- \( n \) = number times asset X was reused
- \( C_i^N \) = Cost of developing or buying asset i instead of reusing X
- \( C_i^R \) = Cost of utilizing asset X, instead of designing a new asset (finding, adapting, etc.)
- \( C_i^D \) = Initial development cost of asset X
- \( T \) = Average life cycle of the technology
- \( \Delta t \) = Time elapsed since first used

For facilities and tooling the drivers of the reusability decision-making process would be:

- Fixed costs and Variable costs, as for parts and systems reusability
- Manufacturing Flexibility\(^1\)
  - Volume/Mix flexibility\(^2\)
  - Product/Changeover flexibility\(^3\)
- Process capability (Is the process delivering what it is expected to deliver? How consistent relative to design tolerances?)
  - Mean Time To Failure, Mean Time To Repair, Throughput
- Reuse effectiveness index.

---

1 Manufacturing flexibility consists of the ability of manufacturing and product design to respond in the shortest amount of time to market changes with products that profitably meet customer wants.
2 Volume/Mix flexibility consists of the ability to change the mix of products within existing capacity limitations (shared versus dedicated plant).
3 Product/Changeover flexibility consists of the ability to convert to a new product with minimum investment cost, and changeover losses.
4- Reusability associated risks

An organization’s strategy for adopting a reusability process should be based on a vision for improving the organization’s way of doing business (at Ford, this would be: Low Cost Producer, Investment Efficient, etc.). To improve the results a company achieves through reuse requires that the company take a comprehensive view of its product development process (i.e., view process as an integrated part of a system of operations for delivering products) and address the technical and non technical issues within this context. Toshiba’s success with reusability is attributed to systematizing reuse to their integrated set of tools, techniques, management procedures, controls, incentives, and training programs.

Particular attention should be paid to avoid reusability with added complexity (such as a slightly modified steering wheel rim section, or a one mm increase in a ball joint diameter). Moreover, reusing a component that fulfills for more than the defined functional requirements should be avoided, or at least carefully dealt with. Overdesign is a major reason for cost increases. Reusability should be systematic only if quality standards, customer needs, technology issues, and competitive costs are warranted.

Figure 2.1 presents two possible cases: one resulting in a low reuse capability, the other in a high reuse capability. The low reuse capability case is characteristic of an ad hoc approach to reuse where the potential opportunities\(^1\) are not identified (represented by dashes). Since the potential opportunities are not known, the target opportunities will likely fall outside the potential opportunities. The target opportunities may also not be explicitly defined (or planned), but represent the total opportunities pursued by individuals. When the target opportunities fall outside the potential opportunities, the actual reuse is constrained to the intersection. The result is a low reuse efficiency since effort is expended on opportunities which do not result in actual reuse.

The second case is characteristic of systematic reuse where the organization identifies its potential opportunities, ensures the target set of opportunities falls within the potential, and has a process which ensure the target is met. The target may not contain the entire set of potential opportunities because the potential benefit from those opportunities outside the target may not be worth the additional reuse investment; i.e., the target is focused on the opportunities with the highest payoff.

---

\(^1\) A reuse opportunity is an occasion where an asset (existing or to be developed) may satisfy a need (current or anticipated); an asset being any tangible resource that may apply to the solution of a problem.
Some notions must be clearly defined before any metric can be put forward.

As stated previously, a reuse opportunity is an occasion where an asset (existing or to be developed) may satisfy a need (current or anticipated), an asset being any tangible resource that may apply to the solution of a problem (design, equipment, etc.). Potential reuse opportunities are the set of reuse opportunities that will result in actual result when exploited. The optimal set of reuse opportunities to be exploited can be defined on the basis of an evaluation of the impact of customer-needs, in terms of change required at each level of product, from both engineering and manufacturing perspectives. The reusability drivers mentioned previously should also be taken into account when making a reuse decision.

Targeted reuse opportunities are the set of reuse opportunities toward which an organization directs its efforts. At Ford Motor Company macro targeted reuse opportunities are defined by the Investment Efficiency Council. As shown in the previous

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1 The approach related to the definition of the optimal reuse levels is developed in Chapter 5.
paragraph, a targeted reuse opportunity may not always be a potential reuse opportunity (e.g., when an asset is developed for reuse for which there is no real need).

We will try in the next chapters to present a set of tools which will help product development people to succeed in doing reusability, before describing a strategic reusability planning and management process which will help any organization in better exploiting potential reuse opportunities when developing products.
Chapter III - The Business Integration Model

1- Definition and scope

1.1- The intent

The intent of the BIM is to support product, process, and technology planning, and enhance business, and engineering efficiency through carryover, commonality, and reusability.

The BIM displays linkages between products desired and the technology and engineering knowledge required to develop them, as well as the manufacturing technology necessary to produce them. The BIM is a simple mapping of technical strengths, technologies, product, and manufacturing strategy relationships. Therefore, it can be used as a planning tool for resource acquisition and allocation needed to support efficient product development and manufacturing systems design.

1.2-The benefits

The benefits of the BIM are multi-fold:

from a value management perspective

- permits assessment of product value relative to resources required
- defines choices available to maximize reusability

---

1 The original business integration model was developed by Ron Andrade, and Don Clausing in 1994, in a joined effort with Ford Motor Company. The objective was to integrate the product, technology, and core competency strategies with support of planned reusability.

from a complexity reduction perspective
- identifies opportunities to avoid complexity increases through reusability

from a decision making perspective
- helps for resource allocation
- defines products, and processes timing

The BIM overcomes major cash drains that plague traditional product development: 
- Matching product and technology strategies overcomes Cash Drain 1: "Technology Push, but Where's the Pull?"
- Customer driven technology development overcomes Cash Drain 2: "Disregard for the Voice of the Customer"
- Product-process compatibility eliminates Cash Drain 4: "Pretend Design" (new and different but not better, not production-intent designs), and Cash Drain 7: "Here's the Product. Where's the Factory".

Some Ford managers who applied part of the BIM to some of their systems noticed:

"What we do not know became more obvious:
- We need additional customer data on all our products
- We do not really know how much reuse we are missing out on
- We are developing basic strengths and technologies without well defined time relationships to products, and processes
- We cannot quantify the adequacy of our basic strengths
- We do not have an effective plan for allocating our basic strengths
- We have intuitive plans, not strategically clear and transferable plans (documented)
- We have a different view of our products than the view of our suppliers
- Some of our subsystems are constantly redesigned without customer benefit".

---

1.3-The reusability side

The BIM is a strategic tool for planning reusability of not only parts and systems, but also facilities and tooling.

Systems, and parts reusability reduces the number of end items and increases the usage of common parts in products and across product lines. Systems, and part reusability entails carryover within product line, carry across from product lines, and modified carry-over/across. This enables the company to concentrate its development resources on the features that are the most valuable to the customer, while reducing its engineering and design costs.

Reusing facilities and tooling, and aligning the product and manufacturing strategies with one another, the cycle planning team can further reduce costs associated with new or in-cycle program changes by creating manufacturing flexibility. Manufacturing flexibility\(^1\) is the ability of manufacturing and product design to respond in the shortest amount of time to market changes with products that profitably meet customer needs. It accommodates changes with the least amount of investment. It integrates product architecture and manufacturing process strategies such that they are common across product lines and consistent from present to next generation of products.

Figure 3.1 displays the Business Integration Model for a product platform - it could also be a product-line. The Product Planning Team should systematically build its technologies upon what it perceives as being the existing, or future core competencies of the company. It should then reuse this technology, as well as existing designs, as much as possible in building new products. By the same token, it should think about: 1) the manufacturability aspect of the product, 2) what basic strengths the company has in terms of production, and 3) how they can be leveraged to support the manufacturing strategy.

The examples displayed at the bottom show how reusability should be approached. Product 4 is a derivative of product 3, and has two carry over subsystems from product 3, the other subsystems are either reused, but modified subsystems, or new designs. External reusability (as displayed in figure 3.1 for product 4) refers to the reuse of subsystems from analogous products (a tractor for instance), or competitive products (a GM part). Sometimes when external reusability do not lead to carry over, it can still be a

\(^1\) As defined by the Ford Design Institute, *Reusability* working paper, January, 1995
Figure 3.1 - The Business Integration Model: overview
good benchmark for building a better design. Xerox Corporation\textsuperscript{1} used design competitive benchmarking in developing a new copier. After evaluating four competitive products, they found that the Canon design for one of the subsystems was functionally superior and its cost was 25\% of the existing Xerox design cost. The Xerox engineers were challenged to \textit{beat the competitive benchmark design or use it}. The result was 85\% cost reduction.

A similar example is displayed for Facilities and Tooling (manufacturing systems) and the possibility to reuse different levels of a plant (from the floor space, transportation devices, to the tools). The Product Planning Team should systematically consider reusing existing production plants, or at least sub-elements of the plant.

\textbf{2- The BIM, a powerful planning tool}

\textbf{2.1- Core competency strategy}

Among the tasks that should be performed when building the BIM, is an assessment of the core competencies. A core competency, or a basic strength, can be any fundamental, or engineering science the company, or one of its departments\textsuperscript{2} masters better than anybody else (Programming, Mechanical Engineering, Precision Mechanisms, Electronic Packaging, Mechatronics, etc.). As mentioned by Clausing [1994], these are not technologies in the sense of being subsystems that could be sold as independent products or incorporated into larger total systems. Rather, these are the basic strengths that support the technologies. It can also be a unique way of doing business (Marketing Skills). Manufacturing core competencies can be tooling and fixture design skills, machine design skills, process design skills, excellence in new process development, or even a flexible work force. A complete set of basic strengths, according to Meyer and Utterbach\textsuperscript{3}, includes customer needs understanding, and distribution channels. Eventually, the Product Planning Team (PPT) should define the core competencies which will be needed for the next technology generations.

\textbf{2.2- Technology strategy}

The PPT should also define the technology portfolio in concert with the Advanced Engineering Division (AED). It should rank technologies according to their development

\begin{footnotesize}
\begin{itemize}
\item[2] Advanced Lighting Technology, or Powertrain for instance.
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stage using the 5/10 years Technology Forecast Map, as shown in Figure 3.21. This map will help the AED to assess the actual state of its Technology Portfolio, and the evolution, and proliferation of technologies over time. Technologies are ranked from unseen to proven, and the migration of each technology is mapped over time. In the example shown below, the WL Technology is unseen in 1996, but becomes an emerging technology in 2001, and reaches the concept ready phase in 2006. This map reflects the list of Concept Ready and Implementation Ready technologies over time. Examples of manufacturing technologies are: 3D Printing, Single Minute Exchange Die (SMED), Poka-yoke, Lean Manufacturing Cell. The 3D Printing technology can be built on the Mechanical Engineering and New Process Development core competencies; The SMED technology could be built on the Tooling and Fixture Design, and Machine Design core competencies.

Following are the definitions of the different technology categories:

**Unseen technologies:** Technologies that may be just an idea or a vision. No real work has been done.

**Emerging technologies:** Technologies or ideas that have been written about.

**Concept Ready:** Working hardware exists. Technology has been shown to work.

**Implementation Ready:** No new invention required. Technology can be programmed.

**Limited application:** Technologies that are in production on a limited number of vehicles or car lines.

**Proven technologies:** Technologies that are in widespread production, at the mature stage of their life cycle.

---

1 This was done by the Advanced Lighting Group at Ford Motor Company, 1996. To protect the company, the map was truncated.
It is also important to prioritize the technology development projects, and stay focused on the technologies that are the most valuable to both the company, and the customer. The Technology Ranking Matrix (Figure 3.3) proposes one way of doing it. This matrix consists of a ranking of the existing or future technologies in terms of value to the customer, value to the company, benchmark position, and sustainability of technological leadership. This matrix will help the Advanced Engineering management to prioritize its development projects, and to concentrate its development resources on the projects that are the most valuable to the enterprise. The evaluations use a three-level rating scale: High = 3, Medium = 2, Low = 1; or Ahead = 3, Equal = 2, Behind = 1 for benchmarking.
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<td>Equal</td>
<td>Ahead</td>
<td>Ahead</td>
<td>Equal</td>
<td>Ahead</td>
</tr>
<tr>
<td>5. Sustainability of technological leadership</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>High</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Score Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 8 11 11 15 13 12 16</td>
</tr>
<tr>
<td>7 8 5 5 2 3 4 1</td>
</tr>
</tbody>
</table>

**Figure 3.3 - Technology Ranking Matrix**
2.3- Product/manufacturing strategy

Manufacturing companies face today unique challenges stemming from the complications of products and markets that are technology driven. As mentioned previously, proactive reusability, and product planning might help the company to plan better the proliferation of its products over time, and better allocate its resources across product programs. Particular attention should be paid to product/process compatibility\(^1\) when defining the product and manufacturing strategies, and a consistent effort should be made to ensure simultaneous development of process specifications and product requirements. This will help the platform, or cycle, planning team to overcome some of the major cash drains that plague traditional product development, mentioned in section 1.2. Simultaneous development of product and manufacturing strategies will enable the company to achieve:

- **Economies of scale through a high commonization of not only systems and parts which increases the output per process, but also product architectures which enables common assembly.** The decision Nissan made to reduce the number of chassis types from 20 to 14 is expected to save $1 billion to the company. In addition the reduction of the number of platforms from 13 to 6 will result in $2 billion savings according to estimations. Notice that parts' inventories should be substantially reduced as demand volatility decreases. This is the result of aggregating parts' demands\(^2\). Note that a design, or manufacturing investment which would have been prohibitive for a specific program, might be affordable if shared by several programs.

- **Reduced engineering expenses through design for modularity, and process reusability.** In the case the platform planning team decides up front to reuse a production facility for a future program, it must provide the product development team with the set of design hardpoints or constraints it needs to meet so that the considered production facility can be reused.

\(^1\) Product/Process compatibility consists of a simultaneous development of product and process strategies when planning for the development of product families, to optimize the utilization of the available resources.

\(^2\) If inventories cover two standard deviations of the demand, 2 \(\sigma\), then for a set of 3 parts for instance, the protection for the aggregated demand -under the commonality assumption- is \(2 \sqrt{(\sigma_1^2 + \sigma_2^2 + \sigma_3^2)}\), instead of \(2 \sqrt{\sigma_1^2 + \sqrt{\sigma_2^2 + \sqrt{\sigma_3^2}}}\), assuming that the demands for the three parts are independent.
- Flexibility, and quick market response enabled by a high commonization magnitude which facilitates capacity transfers across plants, and from a product generation to the next one, when demands for different vehicles are negatively correlated.

- Investment and changeover time reduction as a result of greater use of carryover and common equipment and tooling.

However, and despite all these benefits, the cycle planning team might face dilemmas when the time comes to decide whether to reuse the existing equipment which is not common across the product family, or to buy new equipment to increase commonization. The first option might be better for short term planning, however the second will in the long run prove to be more profitable to the company. The planning team will have to make trade-offs, and build a long term plan to achieve a smooth transition to process commonality.

As explained before, the BIM should help the cycle, or platform, planning team at a lower level, to better plan the proliferation of its products and processes over time, and better allocate its resources. It can be used to reflect the overall strategy of the company, and therefore, show the weaknesses and strengths of each alternative. Many tools were developed to support this strategic planning approach.

The System Reusability Plan (Figure 3.4), for instance, supports the detailed BIM and product/process compatibility, and depicts the reusability levels across products, over time in terms of both engineering and manufacturing. For each subsystem, a clear difference was made between engineering, and facilities and tooling investment. The reason for this, is to enforce the reuse of manufacturing processes as much as we can, especially when design changes are required. As stated earlier, product/process compatibility can sensitively reduce investment costs.

In the example shown in Figure 3.4, the product is a lighting system. This can also be applied to a product line, or a product platform going one step higher.
### Subsystems

<table>
<thead>
<tr>
<th>Subsystems</th>
<th>Engineering</th>
<th>HR Technology</th>
<th>HR Technology</th>
<th>HD Technology</th>
<th>HD Technology</th>
<th>RH Technology</th>
<th>MP Technology</th>
<th>WL Technology</th>
<th>LMS Technology</th>
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</thead>
<tbody>
<tr>
<td>2. Outer lens</td>
<td>F&amp;T</td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>4. Shielding</td>
<td>Engineering</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>5. Slide</td>
<td>Engineering</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
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<tr>
<td>5. Venting</td>
<td>Engineering</td>
<td></td>
<td></td>
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<td></td>
<td></td>
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<tr>
<td>6. Mounting</td>
<td>Engineering</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. Bonding/Sealing</td>
<td>Engineering</td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>8. Light Distribution</td>
<td>Engineering</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
</tbody>
</table>

- **A** = Existing application or potential for identical usage of a previous part
- **B** = Reuse technology or process in different configuration
- **C** = Evolution of previous technology or process
- **D** = All new part/technology/process
- **E** = Develop internal capability
- **F** = Follow US development

**Figure 3.4 - System Reusability Plan**
3- Application to a lighting system, matching basic strengths, technology, and product strategies

Given limited investment and people resources, the Business Integration Model can be used as a strategic planning tool to identify the most important technologies and people to have in place for developing a given customer-driven as well as a cost-driven product. Reuse of systems and technologies can sensitively reduce the development time, increasing by the same token the return on investment on technologies.

The BIM will increase the technology implementation rate, ensuring that the only technologies to be developed are the ones needed for future generational products. Indeed, any technology that does not have enough buyers will not be developed. The current processes for technology deployment in most companies “accept” waste as a fact (25% implementation), refusing to plan for technology implementation - or the technology migration plan - before the concept ready phase. Common sense tells us that one should find customers, identify what they want, and then deliver to them what they are asking for. If one does not have enough customers, he should definitely forget developing his product.

The BIM also increases cooperation between different programs over time to optimally share costs. A prohibitive cost for a given product development program (new process technology for instance), can become reasonable when shared by four, or five programs.

Shown in figure 3.5 is an example of a technology reusability study. For instance, in order to develop a C headlamp technology, one would need mechanical, optical, and software engineering as basic strengths or core competencies. They are required to run the mechanical, optical, and optimization software #1. Finally results gathered from optimization software 1 were utilized to design a C headlamp technology. The focus of the above diagram is not on reusability, but resource allocation across product programs (people, technologies).

We can go a step further, and break down each system into subsystems and analyze the reusability potential of each, as shown in Figure 3.6. 1, 2, 3, and 4 represent some of the lighting systems. Very detailed planning can be done relative to the changes at the system level from a product generation to another. This helps to maximize

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1 Originally this application was carried out by Professor Ron Andrade, in a joint effort with Ford Motor Company. To protect the company, the actual results are not reported in this thesis.
reusability, and to better allocate resources as explained previously. For instance, the UB product has only one brand new system, the light source (1), the other systems being modified or reused from existing products.

A better approach would be to define the manufacturing strategy simultaneously, and think about what plants to reuse for production, and eventually which manufacturing processes.
Figure 3.5 - Overall Linking of Product Strategy with Technology Strategy & Basic Strengths
Figure 3.6 - Detailed system reusability migration plan

REUSE POTENTIAL

A = Existing application or for identical usage of a previous system
→ Direct Reuse

B = Reuse technology or process in a different configuration
→ Modify

C = Evolution of previous technology or process
→ Evolve

D = All new technology/system/process
* All New

○ = Uncertain

Systems
1 = Light Source
2 = Lens
3 = Reflector
4 = Shielding

Figure 3.6 - Detailed system reusability migration plan
Chapter IV - Assessing Customer-driven design, facilities and tooling changes

The previous chapter introduced a strategic planning tool for supporting technology, product, and process planning for a family of products. As will be described later in chapter seven, a cycle, or platform, planning team might have to choose one set of products to be developed among a wide range of possibilities. Sometimes, the BIM and a broad financial analysis will not be sufficient to decide upon how many products should be developed, and how new should be each product to maximize the overall profitability of the corporation.

Hence, a more detailed analysis is needed. A deep understanding of each product expectation is a key step in this process. The following chapter will describe some tools which will help the cycle - or platform - planning team to better assess the type of changes to be made at each product level from both an engineering and manufacturing perspective. The subsequent chapters will present some tools which that help the team determine the resources necessary to develop each product program, as well as the financial return on each of the development alternatives.

We will describe in this chapter:

- the tree analysis which enables the platform team to better assess the design and manufacturing change magnitude required by each product expectation on the product functions, physical designs, and production system.
- the manufacturing reusability template which identifies key manufacturing hardpoints required for manufacturing and assembly reusability.
- the reusability matrices which display the sources of the design and manufacturing solutions for each product expectation.

1- Tree analysis - High level assessment of the design and manufacturing change magnitude required by each product expectation

After having defined the product expectations or specifications, the development team must assess their impact on the functions of the product, and try to determine how each product expectation will change the functional requirements for the product. At the same time, the team must highlight the consequences on the existing design, and associated facilities and tooling.

The first step after the definition of the product expectations, or specifications, consists of an assessment of how each high level product expectation affects the functions of the existing, or previous generational, model. The development team should recall the functional tree built for the previous generational product if it exists, or build one if this was not done before. The functional tree displays the problem to be solved in terms of functional requirements which are derived from the set of specifications that the final product must satisfy. The functional tree should be updated, or established, in a solution-neutral environment, without being biased by preconceived physical solutions. The team must assess how each product expectation will affect the functions of the product based on its experience and experts judgment. Consensus must be reached on each evaluation. This will help the development team to better understand the implications of the new customer needs in terms of the functions the product must satisfy, and therefore better understand the implications of each new product expectation in terms of design, facilities and tooling changes.

Let us consider a machine-tool-design company. One of the products of one of the company’s platforms might be a lathe. Figure 4.1 displays the functional tree - also called functional hierarchy - for a lathe. The development team should define what in the functional tree, which could be the one associated with the previous generation of lathes, should be changed to meet each new customer requirement or product expectation - which can be derived from the House of Quality. This analysis is to be carried at a fairly

1 Other names for product expectations are product attributes, design requirements, corporate expectations, product requirements, and engineering characteristics. The prioritization of the product expectations can be the one resulting from the House of Quality, when the QFD approach has been effectively used by the company or the department. 
2 The set of product specifications, or product expectations can be derived from the QFD House of Quality (Hauser and Clausing, 1988). 
detailed level - including systems and subsystems -, contrary to the BIM analysis which was carried out at the system level.

![Lathe functional tree]

**Figure 4.1 - Lathe functional tree**

Before looking at the subfunctions of the high level functions, the development team must conceptualize a physical design which can satisfy each of the high level new functional requirements dictated by the product expectation considered. For the power supply functional requirement of the lathe, the physical solution for the future generational model might be the existing one if the product expectation considered does not dictate any change on this function of the product. We will then keep a motor drive to fulfill this function. Figure 4.2\(^1\) displays the lathe hardware tree which shows the physical design solutions to each of the functional requirements displayed in the functional tree. If this tree was built for the previous generation of lathes, once again it needs to be updated to meet better the new set of functional requirements associated with each product expectation.

It is of primary importance for the multifunctional team to address the issue of manufacturability, and define the set of manufacturing and assembly processes that will enable the manufacturing and assembly of each system of the product, and eventually the product itself. The production system and the product design must be developed

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concurrently and in close coordination. The benefits of developing simultaneously the design and the production system were described in the previous chapter.

![Lathe Hardware Tree](image)

**Figure 4.2 - Lathe Hardware Tree**

The development team will have to display the set of processes used so far to manufacture the product systems, and focus on the reuse of the existing facilities and tooling. Any design change which meets the functionality of the product as dictated by the product expectations, and permit the reuse of the existing facilities and tooling should be systematically adopted, except when conflicting with long term corporate goals - such as achieving process commonality instead of reusing unique processes.

As mentioned by Suh [1990], the development team must not decompose the first-level functional requirements (FRs) of the product further into lower-level FRs before determining acceptable design and manufacturing solutions for the first-level FRs, for each product expectation.

The analysis described herein will help the development team to determine the product design, facilities and tooling changes dictated by each product expectation. It also helps the team to enforce systematic reusability of design systems, and manufacturing facilities and tooling, and to drive changes by customer wants.
2- Facilities and tooling reusability

Manufacturing investment costs usually represent the major part of the total investment for a product program. At Ford Motor Company, facilities and tooling expenditures represent more than 70% of the total product program investment. This is why a particular effort should be made to reuse the existing facilities and tooling especially when design changes are required. This requires that the platform team define a set of design constraints - or hardpoints - for each manufacturing or assembly process to be reused. These constraints will then provide design engineers with guidance to design for manufacturability.

The set of hardpoints consists of a list of directions to be met when designing a system, so that we can reuse the processes that had been used to produce the previous generational system. These hardpoints or constraints can be displayed in a table where the study items, or systems to be designed, are on the vertical axis; and the areas under constraints on the horizontal axis. We would then have in each cell the product/process compatibility hardpoints that should be maintained to ensure affordability and minimize the impact to manufacturing and assembly. These manufacturing hardpoints are directions and not frozen constraints. They are the specific physical drivers that support the manufacturing targets set by the program team (for instance, reuse stamping plant A).

The manufacturing hardpoints can be related to machine tolerances, part features (radius on corners for casting), thickness of materials for injection molding. Assembly hardpoints might be related to the assembly sequence, the level of automation, etc.

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1 Product/process compatibility is arriving at the best product/process concept by simultaneously optimizing the drivers of investment that are customer wants and cost reduction efforts - including reusability.
3- The product and plant reusability matrices

3.1- Definition and architecture

The product reusability matrix, as described by Clausing [1991], shows the relationship between the sources of the design -system-technology concepts, or end items, integrated into a new product, and the product levels. Breaking down the total product into several product levels enables a more subtle characterization of reusability than the traditional simple reusability of piece parts [Witter 1994]. Following are the definitions of the different product levels and the different sources of technology or design concepts.

The Total System Architecture (TSA) of a product consists of a set of systems, their arrangement, basic composition -in terms of technology-, and structure. It can be considered as the mechanical packaging of the product (including robustness and value of critical design parameters).

A System (S) is a collection of subsystems combined to work as a larger integrated subsystem having the capabilities of all the separate subsystems. It can also be defined as a combination of two or more sets -generally physically separated when in operation- and other assemblies and parts, necessary to perform an operational function or functions.

A Subsystem (SS) is an assemblage of elements within a system (including its general technology, its robustness, and value of critical design parameters). A subsystem is often identified at a level of definition within a system at which an independent development effort is initiated. Complex products have more than one subsystem level.

A Component can be defined as one piece, or two or more pieces joined together, that are not subject to disassembly without destruction or impairment of the part’s designated use.

A partial example of break down of a product into its sub-levels is shown in figure 4.3.

Existing Products are products developed by the company up to the present time, and that were already introduced to the market. Their underlying technologies and concepts should be well understood by the company at this time. Therefore, reusing them should require no or little development efforts.
Competitive products are products developed by the company's direct competitors. Reuse of competitive products, modules, subsystems or components is commonly referred to as reverse engineering.

Analogous products are products developed by another branch of industry, whose technologies, modules, or parts can be imported. Analogous products reusability is also a form of reverse engineering. A tractor would be an analogous product to a car, a printer to a copier.

New means radical innovation or no reusability.

The product reusability matrix is described in figure 4.4. This matrix perfectly describes the static/dynamic spectrum from incremental (I) products to radical (R) products as stated by Clauing [1994]. An incremental change is a freshening action on an existing product, or slight improvement of previous generational product. The majority of the design concepts would be derived from existing products, which is best represented by the first column of the matrix. A radical change is primarily based on new technologies. This type of innovation is best represented by the right column or dynamic side of the matrix. Henderson and Clark [1990] have described two other types of product
innovations or changes - architectural and modular. Architectural products emphasize changes at the total-system-architecture level, while modular products are primarily modified at the lower levels.

<table>
<thead>
<tr>
<th>Levels</th>
<th>Sources</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total System Architecture</td>
<td>Carryover products</td>
</tr>
<tr>
<td></td>
<td>Competitive products</td>
</tr>
<tr>
<td></td>
<td>Analogous products</td>
</tr>
<tr>
<td></td>
<td>New technology</td>
</tr>
<tr>
<td>System</td>
<td>Incremental</td>
</tr>
<tr>
<td>Subsystem level 1</td>
<td>Architectural</td>
</tr>
<tr>
<td>Subsystem level 2</td>
<td>Radical</td>
</tr>
<tr>
<td>End items/Components</td>
<td>Modular</td>
</tr>
</tbody>
</table>

**Figure 4.4 - Product Reusability Matrix [Clausing 91]**

Having identified the necessity of visualizing and quantifying plant reusability, we developed at Ford Motor Company a similar matrix which displays the plant levels and the possible manufacturing reusability sources when designing a new production facility. Following are the definitions of the different plant levels; the different sources of reusability being similar to those of the product planning matrix.

**Plant Layout** is the physical arrangement of the processes and any activity or physical entity that supports this arrangement and its synchronization (transportation devices between processes, inter-processes operators, floor space, buildings, etc.). Eliminating the processes from the plant, you would still have the plant layout.

**Manufacturing process** refers to the series of activities performed upon material to convert it from the raw or semi-finished state to a state of further completion and a greater value.
Manufacturing assembly refers to the series of activities performed upon a number of basic parts or subassemblies to combine them, or join them together to perform a specific function.

The meaning of manufacturing process/assembly layout is similar to plant layout at a lower level. Taking out the machines from a process/assembly, you would have the process/assembly layout.

Equipment includes any machine or physical entity (conveyors, etc.) that is necessary for the performance of a production operation on a product item in a manufacturing process/assembly.

Tooling is defined as a set of required standard or special tools for production of a particular part, including jigs, fixtures, gages, cutting tools, dies, and others. The definition specifically excludes machine tools.

Figure 4.5 displays the structure of the plant reusability matrix.

![Figure 4.5 - Plant Reusability Matrix](image-url)
It is important to keep in mind that these matrices are flexible and more rows can be added if the development team wants to look at the system reusability in more details. Figure 4.6 shows the partial product reusability matrix which would be used for a vehicle.

**Figure 4.6 - Vehicle Reusability Matrix**

3.2- Applications

3.2.1- Better assess reusability degrees

The Business Integration Model reflects the product strategy a company plans to adopt in the development of a product family. It displays the planned reusability levels at the system level. However, when the time comes to compare different product strategies - as will be described in chapter 6 - a more detailed analysis of the reusability degrees should be performed. The level of details at which the development team should look depend on the level of complexity of the product. However, in most cases analyzing the design, facilities and tooling changes to be made to satisfy a product expectation, up to the subsystem level, is enough to decide, upon completion of an economic analysis, what set of products should be developed, and how new should be each product.
The product and plant reusability matrices can help the platform planning team to evaluate the changes to be made at each product level to the existing product, as well as the sources of the design and manufacturing solutions, to 100% meet each product expectation. The first step in such an evaluation consists of a display of all plants that contribute to the production of the previous generational product, or could be targeted for reuse. The team would then have to assess how each product expectation affects the existing product and plants in terms of design, facilities and tooling changes, using the tree analysis to support this process.

Let us consider a simple product x with two systems. Let us assume that the production system associated with this product consists of three plants: manufacturing and assembly plants for system 1 and 2, and a final assembly plant. When developing the next generation of product x - x' -, after the definition of the new set of product expectations, we must assess how each product attribute will affect the existing design, facilities and tooling. We can use the approach displayed in figure 4.7, which consists of defining the contribution of each cell of the product (respectively plant) matrix to the total product (respectively plant) cost, to 100% achieve the product expectation considered. A similar evaluation must then be performed for the subsequent product expectations. This will help the cycle, or platform, planning team in defining the maximum reuse degree which can be achieved at each product level, and still hit 100% customer satisfaction - as will be described in the next chapter.

3.2.2- The reusability matrices as a feedback tool

The product and plant reusability matrices can also be used to provide the development team a visual display of the type of design, facilities and tooling reuse it has planned to achieve before program approval, and later before production ramp-up. It can also help the development team to better assess the type of innovation it has made, and better align its reuse decisions with corporate objectives, in future product development projects. The company might have decided to launch incremental products every year instead of a radical product every four years as mentioned by Clausing [1994]; the reusability matrix will help the company to check whether or not it is following its plans.
Figure 4.8 - Product and production system reusability. Notice that numbers inside the cells represent the contribution of the cell to the product or plant design in terms of dollars. The sum of all cells for a given matrix should be 100%.
Chapter V - Product Planning Matrix

Targets are a qualified set of goals (not just financial) that permits management to assess whether initial development is directionally correct and encompasses all potentially attractive alternatives. Targets are approximate goals to work toward, not contracts to be met\(^1\).

When Ford Motor Company started thinking about reusability years ago, one of their first concerns was to institutionalize it. They decided that this could best be done by assigning to each product program, depending on whether it was a new generational car or a freshening, a target for reusability based on a company worldwide policy, that is complexity reduction. The question that struck me was related to the target defining process, which was based on nothing, except experience and experts judgments. Why 50% parts’ reusability and not 30%, or even 70%? The root problem was actually how to define the best balance between reuse and customer-driven innovation, or change; and therefore, how to define reusability targets for product, and manufacturing engineering.

The following legend is to be used for the graphs inserted in this part.

- Engineering (hours*$/hour = \$$)
- Manufacturing (investment = \$$)

\(^1\) Actual Ford definition of Targets.
1- Definition and scope

The product planning matrix outlines a process for achieving a degree of product change that is clearly visible, suitable to the customer, but avoids unnecessary investment. Marketing, engineering, manufacturing, and accounting must work jointly to identify a design approach to achieve it.

1.1- Intent

The intent of the product planning matrix is to help the multifunctional product development team to:

- Better determine the reusability levels that should be targeted at each product level from both engineering and manufacturing perspectives,

- Better allocate spending and resources, and focus development resources on those features that are the most valuable to the customer,

- Assess the achievement level of the product expectations, after the budget is allocated, and therefore, focus development resources on design changes that have the highest impact on product expectations’ achievement level.

1.2- Benefits

The benefits are multiple. Indeed, this tool will help product planners to:

- Achieve the best balance between reuse and innovation, combining existing designs, and facilities & tooling, with clean-sheet designs, and brand new facilities & tooling, to provide product variety and greater market presence relative to the development effort,

- Assess before decisions are frozen the impact of the team’s decisions on the probable achievement level of the program’s product expectations.

- Consider and analyze different alternatives using an Excel\(^1\) spreadsheet, before choosing the alternative maximizing customer satisfaction and corporate business goals.

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\(^1\) Excel is a registered name of a Microsoft software.
2- Product Planning Matrix - Planning a successful, and affordable product

2.1- Building a market-driven product

Design changes must be driven by customer wants. Any change or improvement to be made to a new generational product should therefore be dictated by a product expectation. Of course, these product expectations need to be prioritized, and the correlation between them identified. This will give to the team guidance on how to spend its budget, and on what requirements it should focus its efforts, as will be described later in this chapter.

2.1.1- Product expectations’ prioritization

Other names for product expectations are product attributes, design requirements, corporate expectations, product requirements, and engineering characteristics. The prioritization of the product expectations can be the one resulting from the House of Quality\(^1\), when the QFD approach has been effectively used by the company or the department. A ranking can also be performed, as described by Lou Cohen\(^2\), on the basis of the assessment of:

- The importance to the customer of each product expectation
- The current satisfaction performance, which reflects the customer’s perception of how well the current product or service is meeting his need
- Competitive benchmarking
- The goal, which is the level of customer satisfaction the team is targeting for each product expectation
- The sales point, which measures your ability to sell a product based on how well each customer need is met.

It is necessary to assign to each product expectation a weight corresponding to its relative importance, the sum of the product expectations’ weight being 100%. An example is displayed in figure 5.1, where we have four product expectations A, B, C, and D. Their relative importance is shown in the first column: prioritization of product expectations.

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2.1.2- Correlation Matrix

This could be once again derived from the House of Quality. Even if you do not use QFD, the correlation matrix must be evaluated. It is aimed at showing the relationships between each pair of product expectations. Indications of negative impact of one specification upon another represent bottlenecks in the design.

Five correlation levels are used to evaluate the correlation level: 1) strong positive, 2) positive, 3) no impact, 4) negative, and 5) strong negative. As stated previously, negative relationships\(^1\) are of primary importance, as satisfaction of both requirements during the design activities will imply trade-offs, especially if the design team fails to fulfill for conflicting requirements. In such a case, the relative importance of each product specification will probably determine whether or not it will be neglected, and the amount of resources to be dedicated to its satisfaction. Nevertheless, the objective is to identify conflicting product expectations early so that particular attention is paid to satisfying both requirements. These negative correlations might call for special planning or breakthrough attempts. It is also to avoid design rework\(^2\). Figure 5.2 shows the structure of the correlation matrix.

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1. For instance, the peak closing force for a car door and the ability to seal out wind, rain, and dust.
2. A producer of integrated circuits was developing an ASIC (Application-Specific Integrated Circuit) for a customer. Analysis of the technical correlations disclosed that certain customer requirements were technically incompatible. Had this incompatibility not been discovered during the product planning phase, the ASIC producer believes they would have wasted several million dollars in preliminary development work before discovering the need to redesign [Cohen 95]
Now that we have prioritized the product expectations and evaluated their interrelationships, which will make our design and manufacturing changes market-driven, it is time to look at the financial aspect of the product program.

2.2- Building a cost-driven product

The objective is to determine costly design systems and manufacturing operations so that a particular effort is made to reuse them, and commonize them across product-lines. It is also to assess the budget necessary to cover a design or manufacturing change at a specific level. This information will be used to support the product development decision process. The cost of all new design, facilities and tooling deployment through the product levels can provide the team with the financial information mentioned. Following is a description of how the expenditures at each product level can be determined.

2.2.1- Assumptions

- Costs of all new design, facilities and tooling (F&T) when derived from past financial data are updated to their current value, using the average compounded inflation rate.
- Costs of all new design, and manufacturing facilities do not vary sensitively over time, except by the average compounded inflation rate.

2.2.2- Costing approach - Expenditure deployment through the levels

The first step in this part is to build a hardware tree for our product. This tree must show all the product systems. Afterwards, the product development team, or product planning team must assess based on its experience, the previous programs and the existing financial data, the total cost of a brand new program, with all new design, facilities and tooling. It should then deploy this total cost through the product levels (Total-system-architecture, systems, subsystems, etc.), to show how much is spent for what. The objective is to display visually the product development costs as they occur at each product level, in terms of engineering as well as manufacturing investment.

At each product level the engineering and manufacturing investment should reflect the very amount of money to be spent at this product level for entirely new design and manufacturing systems. This evaluation can be based on the team’s experience, and existing financial data from previous programs.

In the case of a simple product with two systems, the hardware tree is

```
Total System Architecture

System 1                          System 2
```

Let us assume that the product development team found that the aggregated cost of all-new (0% reusability) design, facilities and tooling is $100,000 based on its experience and past data. The next step is to deploy this $100,000 through the product levels - here the TSA (Total System Architecture), system 1, and system 2. This provides the allocated costs if the product were all new. Later we will calculate the cost reduction that is achieved through reusability. It is very important to separate engineering from manufacturing investment. Figure 5.3 shows the results of such an analysis. For instance, the total-system-architecture engineering\(^1\) will cost about $5,000 if it is all new. The cost of a new total-system-architecture final assembly plant is expected to be $20,000.

The sum of all costs displayed should sum up to the aggregated cost of all new design and manufacturing facilities - $100,000.

\(^1\) This would be the engineering cost of packaging systems 1 and 2.
It is important to keep in mind that the lowest level displayed (system in this example) should be considered as a black box. In other words, end item, or component engineering, and manufacturing investment should be accounted for at this level. In our example, the lowest level is the system level; therefore, the engineering, and manufacturing costs allocated to each system must include the investments related to the design, and manufacturing of their components, or sub-elements.

Some engineers and product managers would prefer to have a tree with costs aggregating as you go up, as suggested by Chapman¹ (Figure 5.4). The cost of engineering the total-system-architecture would then be computed simply as follows: $25,000 - $12,000 - $8,000 = $5,000.

*Aggregated Cost for an all new design and manufacturing facilities (0% reuse): $100,000*

![Figure 5.3 - Cost deployment through the levels](image)

Aggregated Cost for an all new design and manufacturing facilities (0% reuse): $100,000

Figure 5.4 - Accumulated investment cost at each product level

2.2.3- Tie to the product planning matrix

A percentage, reflecting the contribution of engineering and manufacturing facility expenses to the total investment, is computed at each product level. The sum across all product levels should be a 100%, which corresponds to the cost of an all new program ($100,000 in the example considered). In our example, the total-system-architecture contribution to the total expenditures (for an all new program) would be 5% = $5,000 / $100,000 for engineering, and 20% = $20,000 / $100,000 for manufacturing.

The final result of our financial analysis should be plugged into the product planning matrix in the format that is displayed in figure 5.5.
2.3- Defining product-expectation-driven design and manufacturing changes

Next we take the viewpoint of providing complete customer satisfaction, except for cost.

2.3.1- Evaluating the change magnitude required by product expectations at each product level

The objective is to assess the impact of each product expectation at each product level in terms of changes required, from both an engineering and a manufacturing perspective. In other words, we want to know what type of change we need to make at each product level to satisfy our customers, and to be consistent with any corporate, regulatory or manufacturing goals. This evaluation is done by the multifunctional product development team, or multifunctional product planning team based on their experience and knowledge of the past programs.

Later in this chapter, we will iterate to achieve the best balance between cost and the other product expectations.

Figure 5.5 - Cost of all new design, facilities and tooling deployment through product levels
a- Assumptions

- Reusability, and innovation (or change) are measured in dollars saved. For system 1, in the example considered above, 50% reuse of the design would be equivalent to $4,000 = 50% \times $8,000 saved ($8,000 being the cost of a brand new design).

- Complementary changes across product expectations (PEs) are taken into account only once - for the highest priority product expectation

- Distinct changes should be accounted for independently

- In case of conflicting changes, priority is given to most important PE. Trade-offs are made so that no conflicting changes appear on the matrix.

b- Relating design, and manufacturing changes to product expectations

In traditional product planning, design and manufacturing changes have often not been highly correlated, or even driven by product expectations. Overdesign, unnecessary investment, poor reusability, rework, and low profitability products are some of the results of such a negligence. To overcome this problem, the product development, or product planning, team uses the relationship matrix to ensure that design changes, and manufacturing system changes are a high-fidelity translation of corporate product expectations1. The multifunctional team must resolve differences, and converge on a consensus for each cell that best represents the responsiveness of the corresponding design, facilities and tooling changes to the specific product expectation.

A variety of scales can be used in the matrix to assess the impact2 of each product expectation at each product level from a design and manufacturing change perspective. Figure 5.63 shows some of the possible scales. It is important to keep in mind that the reuse degree is interpreted in terms of dollars saved.

---

1 The QFD House of Quality ensures that product expectations themselves are a high fidelity translation of customer wants.
2 To assess the impact means to evaluate the degree of change, dictated by each product expectation at each product level form both a design and manufacturing perspective.
3 The Go/No Go scale was suggested by Brian K. Vought, Manager, Ford Product Strategy office, during a private discussion, August 1996. The Standard scale was suggested by Henry L. Chapman, Program Planning Associate, Ford Advanced Vehicle Technology, during a private discussion, August 1996.
While using the Go/NoGo, and standard scales might be easier for the team, the linear scale makes the differentiation among alternative reuse magnitudes clearer, giving the team a more detailed information related to the type of change it has made later in the development process. For instance, this would enable the team to differentiate between a corporate, a competitive, and an analogous carryover or common system. Indeed, in response to a product specification, reusing a corporate system should cost us less than 20% of the cost of an entirely new design - this would be a change of type 5 - However, reusing a system from an external source, which could be a competitive product or an analogous product, might cost us more than 20% of the cost of a clean-sheet design. It would most likely be a change of type 4/5 for a competitive product, and a change of type 3/5 for an analogous product, which will naturally require more modifications.

The multifunctional team should address each product expectation’s impact on the existing, previous generational design and manufacturing plants separately, starting with the highest priority product expectation.

The design, facilities and tooling changes resulting from the evaluation of the first product expectation should be taken as a reference for the evaluation of the changes deemed necessary for the next product expectation. In case of conflicting changes, trade-offs are to be made, if no technical solution can satisfy both requirements. Early trade-offs should be avoided. The team should always seek a solution that satisfies both requirements. This is often how innovation occurs.

Figure 5.7 shows an example of relationship matrix for our two-system product. It is important to keep in mind that the sum of the changes to be made to a system cannot be more than 100%. Therefore, the sum of the numbers in each column should be greater

---

<table>
<thead>
<tr>
<th>Go/No Go*</th>
<th>Standard**</th>
<th>Linear</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 = New</td>
<td>1 = New (&lt;20% reuse)</td>
<td>1 = New (&lt;20% reuse)</td>
</tr>
<tr>
<td>1 = Carryover/Common</td>
<td>3 = Modified (20%-80% reuse)</td>
<td>2 = Highly modified (20-40% reuse)</td>
</tr>
<tr>
<td></td>
<td>5 = Carryover/Common (&gt;80% reuse)</td>
<td>3 = Modified (40-60% reuse)</td>
</tr>
<tr>
<td></td>
<td>4 = Slightly modified (60-80% reuse)</td>
<td>5 = Carryover/Common (&gt;80% reuse)</td>
</tr>
</tbody>
</table>

**Figure 5.6 - Alternative scales for evaluating the PEs' impact on design, facilities and tooling**
than 5 * (# of PEs - 1), but less than 5 * (# of PEs). In the example displayed in figure 5.7, the sum of the numbers plugged into each column should be greater than 15, but less than 20. The reason for that is that one unit in the one-to-five scale corresponds to 20% of the product’s cost, the maximum change level for the product being 100%.

![Table](image)

**Figure 5.7 - Relationship matrix (These numbers are judged to provide complete customer satisfaction on each PE)**

Note that the greatest changes are made to satisfy PE A. These changes also go far towards satisfying PE B. Therefore, only one small additional change is needed to satisfy PE B. No additional change is needed to satisfy PE C.

**2.3.2- Computing the resulting reuse degree**

a- Reuse degree\(^1\) associated with each product expectation

The reuse degree by product expectation gives an indication of how a given product expectation affects the design, facilities and tooling changes, and the budget necessary to fulfill for each product expectation. This will help the team to better allocate its budget. For instance, a product expectation that is low priority, but requires a high change expenditure, will probably be neglected when we iterate our calculations to achieve the best balance between cost and product expectations satisfaction.

\(^1\) The reuse level here is the percentage of the cost of all new design, facilities and tooling required to meet the product expectation considered.
The reuse degree by product expectation is the cost-weighted sum of the various reuse degrees dictated by the product expectation at each product level. That is

\[
R_{PE_i} = \sum_k \left( C_k^D \cdot R_{PE_i,k}^D + C_k^{F&T} \cdot R_{PE_i,k}^{F&T} \right) / 5
\]

where, \( C_k^D \) is the cost of an all new design at product level \( k \),
\( C_k^{F&T} \) is the cost of all new facilities and tooling at product level \( k \),
\( R_{PE_i,k}^D \) is the design reuse degree dictated by PE\( i \), at product level \( k \),
\( R_{PE_i,k}^{F&T} \) is the facilities and tooling reuse degree dictated by PE\( i \), at product level \( k \).

In the example shown in figure 5.7, the overall reuse degree associated with product expectation A is \( R_{PA} = 49.4\% = \frac{(4 \times 5\% + 2 \times 20\% + 5 \times 8\% + 3 \times 25\% + 1 \times 12\% + 2 \times 30\%)}{5} \). The design reuse degree would be \( 57.6\% = \frac{(4 \times 5\% + 5 \times 8\% + 1 \times 12\%)}{5} \). The facilities and tooling reuse degree would be \( 46.7\% = \frac{(2 \times 20\% + 3 \times 25\% + 2 \times 30\%)}{5} \). The financial weight of engineering design being 25% = 5%+8%+12%, the equivalent for facilities and tooling being 75% = 20%+25%+30%, the overall reuse degree associated with product expectation A (PE A) is therefore \( 49.4\% = 25\% \times 57.6\% + 75\% \times 46.7\% \), which confirms the result obtained above.

Figure 5.8 displays the reuse levels by product expectation, and by system for the example considered previously. The budget necessary to fulfill for PE A will then be \((1 - 49.4\%) \times $100,000 = $50,600\). Notice that this will also produce partial achievement on the remaining PEs, so relatively little additional expenditure is needed to achieve customer satisfaction on all PEs. Besides, the aggregated reuse level \( R_{aggragated} \) for the product is equal to

\[
R_{aggragated} = 100\% - \sum_{i=1}^{n} (100\% - R_{PE_i}) = 100\% - \sum_{i=1}^{n} Ch_{PE_i}
\]

where, \( R_{PE_i} \) is the cost of an all new design at product level \( k \),
\( n \) the number of product expectations.
\( Ch_{PE_i} = (100\% - R_{PE_i}) \) represents the change degree - in terms of dollars- required in our product to meet PE\( i \).

1 In the example considered, at product level 1 we have the total-system-architecture, at product level 2.1 system 1, and at product level 2.2 system 2.
2 \((100,000 * 25\%) * (1 - 57.6\%) = $10,600\) for engineering, and \((100,000 * 75\%) * (1 - 46.7\%) = $39,975\) for facilities and tooling.
Figure 5.8 - Computing design, facilities and tooling reusability degrees by system, and by product expectation, given the relationship matrix - Example

In the team's judgement, as represented in the impact values 1-5, this case will provide complete customer satisfaction on PEs A-D.

Note that this is achieved with only 58.2% change (1-41.8%). Thus, expenditures beyond $58,200 would be difficult to justify.
In the team’s judgment, this aggregated amount of change (58.2% in the example - see figure 5.8) will provide complete customer satisfaction on all of the PEi (note that cost has been excluded from the PEi).

**b- Reuse degree1 by system**

Given the assumptions discussed in 4-a, the design reuse degree for a given system is

\[ R_D^t = 1 - \sum_i (5 - R_{PE_i,k}) / 5 \]

where, \( R_{PE_i,k} \) is the design reuse degree dictated by PEi, at product level k,

\( (5 - R_{PE_i}) / 5 \) being the design change degree dictated by PEi, at product level k.

The facilities & tooling (F&T) reuse degree is computed similarly.

As mentioned previously, there are no overlapping or conflicting changes in the columns of the relationship matrix. Therefore, the change to be made at a product level is the sum of the changes to be made at this same product level to meet each product expectation. For instance, the engineering reuse degree for system 1, according to the relationship matrix shown in figure 5.7 is 80% = 100% - (5-5 + 5-5 + 5-5+ 5-4) / 5. For system 2, the facility and tooling reuse level is 20% = 100% - (5-2 + 5-4 + 5-5 + 5-5) / 5.

The design, facilities and tooling reusability degrees should help the product development team to assess the investment and resources required to meet the product expectations at each product level. An 80% reuse for system 1’s design means that the team needs 20% of the cost of an all new system 1 design to meet the functional requirements of the program. These reusability degrees help to set precise and customer-driven reusability targets. Anything that the product expectations do not affect will systematically be targeted for reuse.

---

1 The reuse level here is interpreted in terms of dollars saved, either for design, or facilities and tooling. It is expressed as a percentage of the approximate cost of an all new design, or facilities and tooling for the system considered.
2.4- Defining the targets achievement\(^1\) degree

We have calculated the cost for all-new (clean-sheet) design, facilities and tooling - $100,000 in the example. We have calculated the cost - $58,200 in the example - of satisfying all of the customer-driven expectations PE\(_i\). Now we will explore trade-offs that further reduce the cost, while only sacrificing a small amount of customer satisfaction on the PEs. The customers might be more satisfied with a lower cost and slightly reduced achievement of PEs.

To do so, we need to first define the achievement degree of a product expectation in response to a design or facilities and tooling change. We need then to define the overall achievement degree of the program, which will be used to find the best balance between cost reduction and the overall satisfaction of the PEs.

2.4.1- Product expectations achievement degree

The degree of product expectation achievement to be expected is computed as the budget allocated to satisfy the product expectation considered, divided by the change degree to be made to the product to meet this product expectation times the total cost of all-new design, facilities and tooling - $100,000 in the example. That is:

\[
A_{PE_i} = \left[ x_i \ast B \right] / \left[ (1 - R_{PE_i}) \ast B_0 \right] = \left[ x_i \ast B \right] / \left[ C_{PE_i} \ast B_0 \right]
\]

where, \(x_i\) is the proportion of the current program’s budget to be allocated to satisfy PE\(_i\), \(R_{PE_i}\) is the product reuse degree driven by product expectation PE\(_i\), \(C_{PE_i} = (100\% - R_{PE_i})\) represents the change degree - in terms of dollars-required in our product to meet PE\(_i\), \(B_0\) is the aggregated cost of all new design, facilities and tooling (0% reuse), \(B\) is the actual program’s budget. \(A_{PE_i}\) is the money to be given, \(x_i \ast B\), divided by the money actually needed to achieve 100% customer satisfaction on PE\(_i\), \(C_{PE_i} \ast B_0\); thus it is the degree of achievement on PE\(_i\)”.

\(^1\) The maximum achievement degree is 100%.
In the previous example (figure 5.8), assuming that 86.9%\(^1\) of the program's budget - that is $58,200 - is allocated to satisfying product expectation A, the achievement degree of this product expectation would be \((86.9\% \times 58,200) / (50.6\% \times 100,000) = 100\%\) - which is not surprising as $58,200 is the cost of providing complete customer satisfaction on all PEs A-D.

2.4.2- Overall achievement of program in terms of product expectations

The overall achievement of the program in terms of product expectations is computed as fellows:

\[
\sum_i (W_{PE_i} \times A_{PE_i})
\]

where, \(W_{PE_i}\) is the weight of product expectation PE\(_i\), \(A_{PE_i}\) is the degree of product expectation PE\(_i\) achievement.

2.4.3- Design, facilities and tooling change achievement degree

A degree of design change achievement is the budget allocated to realize the change divided by the budget actually required to achieve it. Similarly, a degree of facilities and tooling change achievement is the budget allocated to realize the change divided by the budget actually required to achieve it. That is:

\[
A^\ell_i = \left[ y^\ell_k \times B \right] / \left[ (1 - R^\ell_k) \times B_0 \right]
\]

where, \(y^\ell_k\) is the proportion of the current program’s budget to be allocated to achieve the change required at product level k, in terms of design if \(l = D\), facilities and tooling if \(l = F&T\), \(R^\ell_k\) is the reuse degree at product level k, in terms of engineering design if \(l = D\), facilities and tooling if \(l = F&T\), \(B_0\) is the aggregated cost of all new design, facilities and tooling (0% reuse), \(B\) is the actual program’s budget.

If we consider system 1 design (figure 5.8), 80% of the design is carried over; therefore, we have 20% change, or innovation. The cost of designing a new system 1 was evaluated at 8% \(*$100,000 = $8,000. As a consequence, 20% \(*$8,000 = $1600 is the

---

\(^1\) As displayed in figure 9.
budget necessary to achieve the system 1 design change for 100% customer satisfaction. Now if for some reason the budget allocated to make this change is $1,000, the achievement level of system 1 design will be $63\% = \frac{1,000}{1,600}$.

2.4.4- Overall achievement of program in terms of design, facilities and tooling changes

The overall achievement of the program in terms of design, facilities and tooling changes is computed as fellows:

$$\sum_k (C_k^D * A_k^D + C_k^{F&T} * A_k^{F&T})$$

where,

- $C_k^D$ is the cost of an all new design at product level $k$,
- $C_k^{F&T}$ is the cost of all new facilities and tooling at product level $k$,
- $A_k^D$ is the degree of design change achievement, at product level $k$,
- $A_k^{F&T}$ is the degree of facilities and tooling change achievement, at product level $k$.

2.5- Budget allocation for PEs’ optimal achievement magnitude

In this section, we will simply assume that the product development team wants to achieve a 100% customer satisfaction on all product expectations. As seen previously, this can be achieved if it has enough money to fulfill for all design, facilities and tooling changes, as determined by the product expectations - in the example $58,200$.

2.5.1- Assumptions

- A product expectation that requires no changes in both the design, and the manufacturing facilities, will be considered as 100% achieved, and no money will be allocated to its satisfaction.

- The product expectations optimal achievement magnitude is 100%.

2.5.2- Recommended budget allocation by product expectations

As stated before, the optimal budget allocation would be the one that maximizes the overall achievement of the program in terms of product expectations, at 100%. The optimal distribution of spending, and resources is best reached by allocating to each
product expectation the exact proportion of the budget required to achieve complete customer satisfaction on the product expectation considered, that is:

\[ x_i = Ch_{PE_i} \times \left( \frac{B_0}{B_{\text{Required}}} \right) = (1 - R_{PE_i}) \times \left( \frac{B_0}{B_{\text{Required}}} \right) \]

where, \( x_i \) is the proportion of the current program’s budget to be allocated to completely satisfy PE\(_i\),

\( R_{PE_i} \) is the product reuse degree driven by product expectation PE\(_i\),

\( Ch_{PE_i} = (100\% - R_{PE_i}) \) represents the change degree - in terms of dollars- required in our product to meet PE\(_i\).

\( B_{\text{Required}} \) is the budget required to achieve a complete customer satisfaction on all product expectations - $58,200 in the example considered previously.

\( B_0 \) is the aggregated cost of all-new design, facilities and tooling - $100,000 in the example.

**2.5.3- Team decision based budget allocation**

The product development, or product planning team might have a systematic approach, and methodology to allocate spending and resources. In such a case, these numbers should be plugged into the product planning spreadsheet, and the achievement levels should be watched. If this allocation base does not achieve a 100% of customer satisfaction on each product expectation - the budget required to meet all product expectations being the one defined previously ($58,200 in the example) - it is not optimal.

**2.5.4- PE budget allocation: translation into system design, facilities and tooling budget allocation**

Allocating spending and resources to product expectations will help the team to concentrate its efforts on the features that are the most valuable to the customer; however, spending should be deployed through the product levels, to provide a frame of reference, a set of specific expectations to design and manufacturing engineers.

The resources allocation must be proportional to the design or facilities and tooling change cost. For product level k, the proportion of the total program’s budget dedicated to the design change - if \( l = D \) -, or facilities and tooling change - if \( l = F&T \) -, is:
where, \( x_i \) is the proportion of the current program’s budget to be allocated to satisfy \( \text{PE}_i \),

\( R_{\text{PE}_i,k}^{l} \) is the reuse degree to be achieved, at product level \( k \), in terms of design if \( l = D \), in terms of facilities and tooling if \( l = F&T \),

\( C_k^{l} \) is the cost, at product level \( k \), of an all new design if \( l = D \), or all new facilities and tooling if \( l = F&T \),

\( \epsilon = 1e^{-9} \) is a constant used to avoid division by 0 when no change is required by a product expectation.

Figure 5.9 displays the budget deployment through product levels for the example considered in this chapter. Given the aggregated reuse level for the product (displayed in figure 5.8), 41.8\%, and the cost of all new design, facilities and tooling, $100,000, we can compute the budget necessary to have a 100% achievement level of all product attributes:

\[(1 - 41.8\%) \times 100,000 = 58,200.\]

In most cases, the product program budget will be less than actually required to develop the product. Therefore, the team will have to make trade-offs, do more reuse to stay within budget, and achieve an affordable business structure generally enforced by high level management. The next part addresses this issue, through an attempt to build a more realistic approach with regard to design, facilities and tooling changes’ achievement. Nevertheless, this first analysis is sufficient and will provide the product development team with guidance for allocating its budget to realize design, and manufacturing systems’ changes, in the case, senior management wants to achieve a 100% customer satisfaction on all product expectations.
**Budget for Program**

Budget for totally new program $B = \$58,200$

Budget necessary and recommended for 100% achievement of PE:

- Total Cost of all new Design/F&T
- Prioritization of Product Expectations

<table>
<thead>
<tr>
<th>Product Expectations</th>
<th>Budget Allocation</th>
<th>Target Achievement</th>
</tr>
</thead>
<tbody>
<tr>
<td>PE A</td>
<td>5.0%</td>
<td>80%</td>
</tr>
<tr>
<td>PE B</td>
<td>10.0%</td>
<td>40%</td>
</tr>
<tr>
<td>PE C</td>
<td>1.7%</td>
<td>20.0%</td>
</tr>
<tr>
<td>PE D</td>
<td>8.0%</td>
<td>100%</td>
</tr>
<tr>
<td>PE E</td>
<td>25.0%</td>
<td>100%</td>
</tr>
<tr>
<td>PE F</td>
<td>51.2%</td>
<td>100%</td>
</tr>
<tr>
<td>PE G</td>
<td>93.6%</td>
<td>100%</td>
</tr>
<tr>
<td>PE H</td>
<td>94.0%</td>
<td>100%</td>
</tr>
<tr>
<td>PE I</td>
<td>1.6%</td>
<td>100%</td>
</tr>
<tr>
<td>PE J</td>
<td>1.4%</td>
<td>100%</td>
</tr>
<tr>
<td>PE K</td>
<td>58.2%</td>
<td>100%</td>
</tr>
</tbody>
</table>

**Overall Achievement**

- In terms of Design/F&T: 100%
- In terms of Product Expectations: 86.9%

**Budget for Program $B = \$58,200$**

Figure 5.9 - Product planning matrix. Budget deployment through product levels. Case where the budget for the program is exactly what is needed to achieve complete customer satisfaction on each PE.$B = \$58,200$
3- Achieving the best balance between reuse and innovation - Enhancing reusability degrees to achieve affordability

The objective of any well-managed organization is to be investment efficient. That is to say, minimize investment while optimizing customer value to achieve an affordable product. Today, many product program teams are still costing product alternatives that are not consistent with their investment targets, being sometimes hundreds of millions of dollars over their investment target, but still not achieving 100% of the product expectations achievement.

As stated before, the product planning matrix will help the team to minimize its expenses, by systematically carrying over items that the product expectations do not affect. However, this will not be sufficient in some cases, and the team will still need to cut its expenditures. In such a case, it needs to increase its reusability degrees while still trying to meet the product expectations, and therefore achieving a high customer satisfaction level.

The team needs then to build a second product planning matrix where it tries to eliminate the design, and manufacturing system changes that have the lowest impact on the overall achievement of the program in terms of product expectations - as defined previously -, but which are costly. This will decrease the spending, keeping customer satisfaction relatively close to its maximum level. In this matrix, the team should always achieve 100% of its targets. A design, or manufacturing system change cannot be half done. It is a go / no go policy.

3.1 Defining the reusability degrees which maximize the overall achievement magnitude of the program for a given budget

When the budget for the product program is less than the budget required to achieve a 100% customer satisfaction on PEs - $58,200 in the example - the product development team should adjust the product-expectation-driven reusability degrees to stay within the constraint of its affordability targets.

Several iterations might be necessary, before the team finds the best alternative. In the example shown in figure 5.8, the product planning team, or product development

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1 A manufacturing system is a set of machines, transportation elements, computers, storage buffers, and other items that are used together for manufacturing. People are also part of the system. Alternate terms are factory, production system, production facility.
team would need $58,200 = 58.2\% \times \$100,000 to entirely meet all product expectations. It has only $50,000 that it must use such as to maximize customer satisfaction, defining achievable change degrees\textsuperscript{1}. Figure 5.10 displays one possible alternative of doing more reuse to stay within budget.

If it decides to reuse 60\% of system 2 facilities and tooling, instead of a 20\% reuse, it will stay within budget. Of course, the product expectation A achievement level will be affected as its impact on system 2 manufacturing systems was evaluated at 2/5 (highly modified), whereas the team decided to make a change of type 4/5, using and adapting existing equipment. As a consequence the overall achievement level of the program in terms of product expectations will be not more than 88\%; the same metric related to design, facilities and tooling being 85\%, as shown in figure 5.10. The budget necessary for such a change would be 92.4\% of the actual one.

Another alternative would be to make a change of type 4/5 for system 1 manufacturing system changes, and a change of type 3/5 for system 2 manufacturing system changes. This would result in a higher overall achievement level of the program in terms of product expectations (89\% vs. 88\%) and lower achievement in terms of design, and manufacturing changes as displayed in figure 5.11. The budget actually necessary to achieve these changes would be no more than 94.4\% of the actual program’s budget. The team can do several iterations until it finds the best alternative.

However the fastest way of finding the reuse degrees that achieve the highest program achievement magnitude would be to solve the following linear programming problem, where

\textsuperscript{1} Remember that the team should only plan for changes it can afford - which it can completely achieve.
Figure 5.10 - Adjusted product planning matrix, alternative #1. This matrix reflects the change degrees decided by the team, based on the ones driven by the product expectations, and the available budget for the program. The team does more reuse than is dictated by the market to stay within budget.
Figure 5.11 - Adjusted product planning matrix, alternative #2. This matrix reflects the change degrees decided by the team, based on the ones driven by the product expectations, and the available budget for the program. The team does more reuse than is dictated by the market to stay within budget.
\[
\max_{R_{PE_i,k}} \left\{ \sum_{i=1}^{n} \left[ \frac{(Ch_{p_i}^1 \ast B) / (Ch_{p_i}^0 \ast B_0)}{W_{PE_i}} \right] \right\}
\]

given \( Ch_{p_i}^1 = 1 - \sum_{1 \leq k \leq m, l=D,l=F&T}^{n} (C_{k}^l \ast R_{PE_i,k}^l) / 5 \)

subject to, \( \sum_{i=1}^{n} (Ch_{PEi}^1 \ast B_0) \leq B \)

\( R_{PE_i,k}^0 \leq R_{PE_i,k}^1 \leq 5 \) for \( 1 \leq k \leq m \) and \( 1 \leq i \leq n \)

where, \( R_{PE_i,k}^l \) is the reuse degree to be achieved, at product level \( k \), in terms of design if \( l = D \), in terms of facilities and tooling if \( l = F&T \), related to satisfying product expectation \( i \). It is the variable in this optimization problem,

\( R_{PE_i}^0 \) is the product change degree driven by product expectation \( PE_i \), as computed in the previous section,

\( R_{PE_i}^1 \) is the product change degree decided by team to meet \( PE_i \),

\( W_{PE_i} \) is the market-driven weight of product expectation \( PE_i \),

\( B_0 \) is the aggregated cost of all new design, facilities and tooling,

\( B \) is the actual program’s budget.

\( C_{k}^l \) is the normalized cost, at product level \( k \), of an all new design if \( l = D \), or all new facilities and tooling if \( l = F&T \),

\( n \) is the number of product expectation,

\( m \) is the number of product levels - that is one (for the total-system-architecture) plus the number of systems plus the number of subsystems.

---

1. This condition reflects the fact that we cannot spend in the design and manufacturing changes more than the budget we have.

2. This means that we are going to do more reuse to stay within affordability.
In the example, the optimization problem would be:

\[
\begin{align*}
\max_{R^i_{PE,k}} & \left\{ \left[ Ch^1_{PE_A} \times \$50000 \right] \big/ (50.6\% \times \$100000) \times 50\% \right\} \\
& + \left\{ \left[ Ch^1_{PE_B} \times \$50000 \right] \big/ (6\% \times \$100000) \times 30\% \right\} \\
& + \left\{ \left[ Ch^1_{PE_D} \times \$50000 \right] \big/ (1.6\% \times \$100000) \times 5\% \right\} \\
\text{given That} \quad Ch^1_{PE_i} &= 1 - \left\{ \left( 5\% \times R^D_{PE_i,1} \right) / 5 + \left( 8\% \times R^D_{PE_i,2} \right) / 5 + \left( 12\% \times R^D_{PE_i,3} \right) / 5 \\
& + \left( 20\% \times R^{F&T}_{PE_i,1} \right) / 5 + \left( 25\% \times R^{F&T}_{PE_i,2} \right) / 5 + \left( 30\% \times R^{F&T}_{PE_i,3} \right) / 5 \right\} \\
\text{subject to,} \quad (Ch^1_{PE_A} + Ch^1_{PE_B} + Ch^1_{PE_C} + Ch^1_{PE_D}) \times \$100,000 \leq \$50,000 \\
R^0_{PE,i,k} \leq R^1_{PE,i,k} \leq 5
\end{align*}
\]

which can be solved using a linear programming computer solver\(^1\).

It is important to keep in mind that the money required to achieve the change degree decided by the team for each product expectation, corresponds to the actual money which will be allocated to meet this change degree. The team should not take into account design and manufacturing change alternatives which would make the necessary budget to actually realize them greater than the budget it has, or it expects to be given - which is reflected by the first constraint in the linear programming optimization problem.

As displayed in the example presented in figure 5.9, the achievement level of the team targeted changes should always be 100%. However, the aggregated number shown in the %-budget-required-to-meet-the-team’s change-degree-decision column must be less than 100% if we want to stay within affordability.

### 3.2- Defining the cost of a targeted overall achievement magnitude

In most cases, the team will target a certain overall achievement magnitude for the product expectations; and will then try to define the design, facilities and tooling change degrees which achieve this magnitude at a minimum cost.

The approach described in the previous example is easier from a computational point of view - given a certain budget it is easier to determine the change degrees which maximizes the overall achievement of the program in terms of product expectations.

\(^1\) Many softwares for solving optimization problems are available in the market.
Therefore, we will use the tabulation technique, which consists of finding the optimal change degrees for extreme values of the budget. We will then iterate, trying to narrow the interval from which the value of the budget is chosen, until we determine the exact value of the budget which corresponds to the targeted overall achievement magnitude. At this point the team would know what the minimum cost for achieving a given customer satisfaction magnitude is.

In the example, we can try to evaluate the minimum cost of achieving a 90% achievement level. If the budget were $50,000, the achievement magnitude in terms of PEs would be 89%. If it were $51,000, it would be 91%. Therefore, the minimum cost for achieving 90% customer satisfaction is approximately $50,500.

4- Balancing investment costs with production costs, and sales volumes

The Product Planning Matrix should provide product planners with a powerful tool to achieve the highest customer satisfaction level for a minimal investment in design, facilities and tooling. This will be done through a systematic reuse of systems that are not affected by customer requirements or regulatory requirements - thus eliminating none market-driven changes -; but also, through an optimal allocation of resources to the design and manufacturing changes that have the highest impact on the achievement magnitude of customer satisfaction, and corporate goals. It will also help the platform planning teams to better share their investments across product-lines through systematic commonization of systems, facilities and tooling that are not affected by product expectations.

However other constraints - than investment - need to be taken into account before making final investment decisions, such as the production cost, and the sales volume. A low investment (with a high degree of reuse) might not be the best option, especially if a higher investment results in a lower variable cost, or a higher quality product, which is usually associated with higher sales volumes. Moreover, as lower investment entails lower customer satisfaction, it might affect the sales volume.

This suggests that it is necessary to take into account all parameters related to the full product cost, and the net present value of the project before making a final decision related to design and manufacturing investment.

---

1 Which maximizes the overall achievement of the program in terms of product expectations.
The next chapter presents a two phase approach to analyzing the economic value of a product program. This will help the platform team to choose between alternative design, facilities and tooling alternatives.
Chapter VI - Economic Analysis

During a product development process, a team has to make several decisions that can affect the future profitability of the product:

- What magnitude of customer satisfaction should be targeted: 80% with a low product price, or 100% with a high product price? How would this affect sales volumes, and after-sales-service (warranty costs...)?

- How much should we spend in design and manufacturing investment? What reuse degrees should be targeted at each product level? How would this affect the production cost?

- How the team’s decisions will affect the full product cost, the operating income of the business unit, and the net present value of the program?

The team will inevitably face dilemmas and will need to make prompt decisions. A deep understanding of interrelationships between the cost and revenue drivers as well as a detailed accounting of estimated costs, and revenues will help the product development team to make the right decision when facing many alternatives. Especially when dealing with reusability, the team needs to assess the financial consequences of each of the alternatives, so that it can adopt the most beneficial option.

This chapter presents:

- An attempt to understand the interrelationships existing between investment costs, customer satisfaction, sales forecasts, marketing costs, and production costs.
- A comparison of a traditional and misleading job costing system to the activity-based costing system, which enables the company to better allocate expenditures to products.

- A costing approach to compute product costs, and profit margins; and to help the product development team to assess how its decisions affect the product cost and the profit per unit given the market price.

- A financial model to compute the net present value (NPV) of a product program, which will help the PDT to assess how its decisions affect the NPV.

If we spend 10% more in design, or if we reuse an overdesigned\(^1\) system instead of building a new one, etc., how would that affect the cost of our product, our profit margin, our market share, our operating income, the NPV of our project?

1- Costs and revenues inter-dependencies

It is of critical importance to understand how our investment decisions affect other costs, and sales revenues through customer satisfaction. In the previous chapter, a model was presented which depicts how investment decisions affect customer satisfaction. We need to go one step further and define how sales volumes relate to the customer satisfaction magnitude.

A very simple model is a linear model in which one assumes that the customer satisfaction - as defined in the previous chapter - and sales volumes are linearly correlated. Another approach would be to use a regression analysis based on past data, to determine how sales and customer satisfaction relate to each other. This relationship is beyond the scope of this thesis.

The product development team should also take into account variable costs in making investment decisions. A standard procedure consists of a systematic evaluation of the production costs associated with a given investment scenario.

This will help the team focus on investment scenarios that are consistent with the corporate goals and the affordability targets.

\(^1\) Which fulfills more functional requirements than demanded.
2- Activity-based costing vs. traditional job costing

Before any economic analysis can be performed, we need to verify the validity of the models used to compute our product related costs - production costs, marketing costs, distribution costs... It is clear that if our evaluation of the expenses per product is defective, the economic analysis and profitability study that follow will be entirely erroneous.

The overall purpose of accounting is two-fold: first, to ascertain how much it costs the enterprise to provide products and services to its customers, and second, to determine how much the company gains in profit from these endeavors. In fact, any flaw in the set of assumptions that govern these two assessments can have serious repercussions for the enterprise.

2.1- When traditional job costing fails

Job costing is a costing system where the cost of a product is obtained by assigning costs to a distinct, identifiable product. This costing system has two major characteristics:

- Overhead is aggregated into large pools.
- Overhead is allocated to jobs\(^1\) based on a volume-related driver such as direct labor.

The general approach to Job Costing consists of 5 steps:

- Step 1: Identify the job that is the chosen cost object\(^2\).
- Step 2: Identify the direct cost categories for the job.
- Step 3: Identify the indirect cost pools associated with the job.
- Step 4: Select the cost allocation base to use in assigning each indirect cost pool to the job.
- Step 5: Develop the rate per unit of the cost allocation base used to allocate indirect costs to the job.

The most common job costing system consists of two pools for direct costs - materials cost and labor cost -, and a unique large pool for indirect costs - so called overhead costs. The indirect cost allocation base is the labor-hour. This accounting system demonstrated its performance in an era of labor intensive products (where labor accounted for 75 to 95% of total cost). Today cost patterns have changed significantly.

---

\(^1\) Jobs are identifiable units or small batches of reasonably homogeneous products.

\(^2\) A cost object is anything for which a separate measurement of costs is desired.
due to new product and production technologies, and the labor contribution to the total cost is generally below 10%. In companies where overhead is still allocated on the basis of labor hours, the accounting departments continue to expend significant time and energy to track labor elements that have become increasingly of secondary importance, and more misleading than anything else. It is important to keep in mind that even if the overhead allocation-base was the machine-hour (as we moved from a labor-paced to a machine-paced environment), the job costing system would still fail.

Today, the job costing approach fails for many reasons: technological changes which have greatly reduced the importance of direct labor, product variety as volume-based drivers do not capture changes in overhead consumption, large size and heterogeneity of cost pools... Many companies still take irrelevant decisions in terms of investment and production because of a misleading accounting system. And any company committed to the path of world-class products, still using these systems, may get a distorted and misleading picture of its present performance, challenges, and improvement options.

Following are some of the symptoms of an outdated cost system:

- The outcome of bids is difficult to explain.
- Competitors’ prices appear unrealistically low.
- Products that are difficult to produce show high profits.
- Operational managers want to drop products that appear profitable.
- The company has a highly profitable niche all to itself.
- Some departments use their own accounting system
- Product costs change as financial reporting regulations do.

It is of critical importance to the company to have a relevant measurement of the way jobs, products, services, and customers differentially use the resources of the organization. These changes can require additional direct cost tracing, or more indirect cost pools.

2.2- Activity-based costing

Activity-based costing (ABC) is a costing system that focuses on activities as the fundamental cost objects. It uses the cost of these activities as the basis for assigning costs to other objects such as products and services. ABC can be characterized as follows:

- Cost pools are identified by activities.
Activities are characterized by overhead cost hierarchy (figure 6.1).
It has a sophisticated identification of cost drivers, which are related to activities

There are many advantages to the ABC approach. The use of non-unit causal drivers provide more accurate product costs for decision making. An analysis of causal drivers using an ABC approach gives companies a better understanding of the economics of the production process. This information can be used to focus improvement projects on the non-value-added activities that drive many costs (e.g. machine set ups, product complexity). The overhead hierarchy can provide useful information on the avoidable and unavoidable costs for a given decision.

In the next sections, we describe a quantitative approach for economic analysis of a product program, which can support the product development team by showing the financial impact of their decisions on the profitability of the product. This economic analysis can also support the reusability decision-making process by answering such questions as (1) how much reuse should we target to hit our target cost and achieve our targeted profit margin and (2) what is an optimal net present value for the program?
Figure 6.1 - The hierarchy of factory operating expenses (Cooper and Kaplan, "Profit Priorities from Activity Based Costing". 1991)

* = If plant makes more than one product, this expense is allocated on the basis of value added.
3- Target costing\(^1\) - Proactive costing for a better decision-making process

After the team has defined several scenarios, it needs to choose the ones which will most benefit the company, ensuring the targeted operating income and the desired program net present value. The first step is to assess the market price for the product to be sold, which will later become the target price. The target price is the estimated price potential customers will be willing to pay for a product. This estimate is based on an understanding of the customer-perceived value for a product and the responses of competitors. The target cost is the estimated long-run cost of a product that when sold enables the company to achieve the targeted income. Target cost is derived by subtracting the target profit margin from the target price.

To achieve its target cost, the company often has to improve its design, and production processes, or lower its spending - through reusability for instance. Today, many worldwide companies use this approach to better assess the financial implications of their investment decisions, and better consolidate their positioning in the market.

3.1- Target costing process

Developing target prices and target costs requires the following iterative steps:

Step 1: Develop a product that will satisfy the customer needs, and corporate musts. Quality Function Deployment can be of great benefit in designing such a product.

Step 2: Identify a target price based on:
   (i) Customers’ perceived value for the product, and
   (ii) Potential competitors’ prices.

   In this case a deep market research should be done. Competitive benchmarking might also be of great benefit in defining the target price.

Step 3: Derive a target cost by subtracting the desired profit margin from target price.

Step 4: Perform value engineering\(^2\) and consider several investment scenarios which might be consistent with the target costs. Reusability is a strategic enabler from that perspective.

---

\(^1\) Target costing is an important form of market-based pricing. The market-based approach always starts by asking, “Given what our customers want and how our competitors will react to what we do, what price should we charge?”.

\(^2\) Value engineering is a systematic evaluation of all aspects of research and development, design of products and processes, production, marketing, distribution, and customer service, with the objective of reducing costs while satisfying customer needs.
Two key cost-related concepts important in value engineering are cost incurrence, and locked-in costs. Successful value engineering requires drawing a careful distinction between when costs are incurred and when costs are locked in.

Step 5: If target cost is achieved for one of the investment alternatives, select scenario. Otherwise refine product design and begin again at step 1.

### 3.2- Cost incurrence and locked-in costs

Cost incurrence occurs when resources are actually utilized. Cost systems recognize and record costs only when cost are incurred.

Locked-in costs are those costs that have not yet been incurred, but that will be incurred in the future on the basis of decisions that have already been made.

It is very important to distinguish between these two types of costs. It is always difficult to reduce costs that have already been locked-in. Figure 6.2\(^1\) displays a typical pattern of cost incurrence and locked-in costs for a standard manufactured product. The point of the graph is to emphasize the wide divergence between when costs are locked in and when those costs are incurred. Most costs are locked in well before they are actually incurred. Likewise, once design is set, costs are difficult to influence. Therefore, most of the scope for cost reduction is in the design phase:

- Better designs reduce scrap, rework, customer service, and warranty costs.
- Simpler designs reduce direct labor and machine hours and testing and inspection costs
- Using fewer parts reduces ordering and handling costs...

From such a perspective, reusability is a strategic enabler. While focusing the development team on critical issues related to customer wants, it helps improving existing designs and building on the work done before, making the best benefit from corporate experience.

---

3.3- Product profitability evaluation - Example

There are several basic cash inflows and cash outflows in the life cycle of a product. Cash inflows come from product sales. Cash outflows include spending on research and development - or advanced engineering; design and manufacturing investment costs; marketing costs; distribution costs; and customer-service costs; and the cost of goods sold that are the ongoing production costs such as raw materials, labor, and overhead.

A product is profitable if it generates more cumulative inflows than cumulative outflows. When developing a product, the team must think its decisions in terms of how it affects the unit cost, and the profit margin per unit; it must also take into account the overall profitability of the program over its life-cycle - as will be presented in part 2 - and other external constraints such as competition (a capital expenditure might not have a payback within two or three years, but it still may be necessary so as not to fall behind industry sometime later).
Figure 6.3 depicts how revenue, full product costs, and operating income relate to each other. It is important to keep in mind that the unit price is market-driven; therefore it is given when the product program is first initiated. The desired margin is also defined as a corporate requirement for the program by high level managers. At this point, the cost of goods sold, and the operating costs are the only profit drivers the team can influence.

Consider product X', the new generation of product X. The company (Abyss) producing X, very concerned about severe price competition, decides to design a new version of its product to consolidate its position in the market. Abyss’ management believes it must respond aggressively by reducing its actual price by 20% (from $200 to $160), as the competition is targeting a 15% reduction in its price. Management also wants a 15% target operating income on sales revenue. The marketing manager forecasts an increase of annual sales from 400,000 to 600,000 units resulting from price reduction. Therefore,

Total target sales revenue = $160 * 600,000 = $96 million.
Total target operating income = 15% * $96 million = $14.4 million.
Target operating income per unit = $14.4 million / 600,000 units = $24 per unit.
Target cost per unit = Target price - Target operating income per unit = $160 - $24 = $136.
Total current operating cost for product X = $75,000,000.
Current operating costs per unit of X = $75,000,000 / 400,000 = $188 per unit.

In designing the new version of product X, the team should focus its resources on the features that are the most valuable to the customer, and carry over any system or manufacturing process that is not conflicting with customer requirements. A drastic reduction of design, and manufacturing investment can help the team to reduce the full product costs very efficiently; as is displayed in figure 6.3, which shows how reusability of existing designs and manufacturing processes can help in achieving the target cost (this reflected by research and development, and design and manufacturing cost reduction).

---

1 Target costing often causes designers to favor lower-priced new systems, or parts, over existing parts that may be slightly more expensive. Other costs associated with the requirements of new systems, or parts, more processes, more support tasks, numbers of parts, and expected inventory turns are rarely considered.
<table>
<thead>
<tr>
<th>Total Revenue and Costs</th>
<th>Unit Revenue and Unit Costs</th>
<th>Total Revenue and Target Costs</th>
<th>Unit Revenue and Unit Costs</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Product X</strong></td>
<td></td>
<td><strong>Product X’</strong></td>
<td></td>
</tr>
<tr>
<td>for 400,000 units of X sold</td>
<td>B = A / 400,000</td>
<td>for 600,000 units of X’ to be sold</td>
<td>B’ = A’ / 600,000</td>
</tr>
<tr>
<td>Revenue</td>
<td>$80,000,000</td>
<td>$160.00</td>
<td>$96,000,000</td>
</tr>
<tr>
<td>Cost of goods sold</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct materials costs</td>
<td>$25,000,000</td>
<td>$62.50</td>
<td>$35,000,000</td>
</tr>
<tr>
<td>Direct manufacturing labor costs</td>
<td>$5,000,000</td>
<td>$12.50</td>
<td>$7,000,000</td>
</tr>
<tr>
<td>Direct machining costs</td>
<td>$6,000,000</td>
<td>$15.00</td>
<td>$8,000,000</td>
</tr>
<tr>
<td>Manufacturing overhead costs</td>
<td>$0.00</td>
<td>$0.00</td>
<td>$1,000,000</td>
</tr>
<tr>
<td>Ordering, shipping, and handling costs</td>
<td>$1,000,000</td>
<td>$2.50</td>
<td>$1,000,000</td>
</tr>
<tr>
<td>Testing, inspection, and rework costs</td>
<td>$800,000</td>
<td>$2.00</td>
<td>$1,000,000</td>
</tr>
<tr>
<td>Administrative cost</td>
<td>$1,200,000</td>
<td>$3.00</td>
<td>$1,300,000</td>
</tr>
<tr>
<td><strong>Total cost of goods sold</strong></td>
<td>$39,000,000</td>
<td>$97.50</td>
<td>$53,300,000</td>
</tr>
<tr>
<td>Operating costs</td>
<td>$0.00</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Research and Development costs</td>
<td>$5,000,000</td>
<td>$12.50</td>
<td>$3,300,000</td>
</tr>
<tr>
<td>Product, and process design costs</td>
<td>$20,000,000</td>
<td>$50.00</td>
<td>$10,000,000</td>
</tr>
<tr>
<td>Marketing costs</td>
<td>$6,000,000</td>
<td>$15.00</td>
<td>$8,000,000</td>
</tr>
<tr>
<td>Distribution costs</td>
<td>$2,000,000</td>
<td>$5.00</td>
<td>$3,000,000</td>
</tr>
<tr>
<td>Customer-service costs</td>
<td>$3,000,000</td>
<td>$7.50</td>
<td>$4,000,000</td>
</tr>
<tr>
<td><strong>Total Operating costs</strong></td>
<td>$36,000,000</td>
<td>$90.00</td>
<td>$28,300,000</td>
</tr>
<tr>
<td><strong>Full Product costs</strong></td>
<td>$75,000,000</td>
<td>$187.50</td>
<td>$81,600,000</td>
</tr>
<tr>
<td>Operating income</td>
<td>$5,000,000</td>
<td>$12.50</td>
<td>$14,400,000</td>
</tr>
</tbody>
</table>

Cost reduction achievement level 100%
Desired operating income achievement level 100%

Figure 6.3 - Product profitability of X'. Targets achievement level. Note that X' is the next generational model of product X.
The numbers in the first two columns of the table are actual numbers. The ones in the last two columns are estimates.
As displayed in this table, a drastic reduction of design, and manufacturing investment can help the team to reduce the full product cost significantly.
Besides investment costs, reusability and commonality can help the product development team to achieve economies of scale through volumes, and to take advantage from the experience curve\(^1\) (figure 6.4).

![Figure 6.4 - Typical Experience Cost Curve](image)

4- Financial model for program’s Net Present Value assessment - Making of long-term planning decisions for investment

After the product costing phase, the team needs to assess the long term profitability of the product program. The selected approach to do that is the Net Present Value method.

4.1- Net Present Value method

This financial analysis of product programs focuses on cash inflows and outflows rather than operating income as seen in the previous section. This approach recognizes that the use of money has an opportunity cost; and because it explicitly and routinely weighs the time value of money, it is usually the most comprehensive method to use for long-run decisions. The Net Present Value is a discounted cash flow method of

---

\(^1\) This effect has been proven based on the increase in efficiency when a task is performed repeatedly.
calculating the expected net monetary gain or loss from a project by discounting all expected future cash inflows and outflows to the present point in time, using the appropriate rate of return\(^1\). A product program is acceptable if its net present value is positive; which means that the return from this project exceeds the cost of capital\(^1\).

It is of critical importance to assess the net present value of the project periodically, by quarter for instance; and verify that cash outflows are spread enough to be supported by the company.

The analysis can be conducted in four steps:

**Step 1:** Draw a sketch of relevant cash inflows and cash outflows from the time the program starts, until production stops.

**Step 2:** Compute each period's cash flow adding cash inflows to cash outflows.

**Step 3:** Choose the appropriate rate of return, and compute the present value of each period’s cash flow.

**Step 4:** Sum the present values to determine the net present value.

### 4.2- Manufacturing example

The basic categories of cash flows for a typical product program are:

- Research and development cost (new technologies’ development, advanced engineering)
- Design and manufacturing investment costs
- Production cost, also called cost of goods sold (direct costs, and indirect costs)
- Marketing cost (launch cost, promotion costs)
- Distribution cost
- Customer-service cost
- Sales revenue
- Tax expenses
- Miscellaneous inflows and outflows (working capital, cannibalization, salvage cost...).

The numerical values of the cash flows come from budgets and other estimates obtained from the multifunctional product development team. The financial estimates

\(^{1}\) The minimum return that the company could expect to receive elsewhere for an investment of comparable risk.
must be merged with timing information. This can be done considering the project schedule and sales forecast.

Let us consider an example to illustrate the net-present-value financial analysis. Product X’ has the following estimated budgets, production costs, and sales volume forecasts:

<table>
<thead>
<tr>
<th>Type of cash flow</th>
<th>Product X’ (estimate)</th>
<th>Product X (actual)</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Research and development (R&amp;D):</td>
<td>$3.3 million</td>
<td>$5 million</td>
</tr>
<tr>
<td>- Design and manufacturing investment cost:</td>
<td>$10 million</td>
<td>$20 million</td>
</tr>
<tr>
<td>- Production cost:</td>
<td>$53.3 million</td>
<td>$39 million</td>
</tr>
<tr>
<td>- Marketing cost:</td>
<td>$8 million</td>
<td>$6 million</td>
</tr>
<tr>
<td>- Distribution cost:</td>
<td>$3 million</td>
<td>$2 million</td>
</tr>
<tr>
<td>- Customer-service cost:</td>
<td>$4 million</td>
<td>$3 million</td>
</tr>
<tr>
<td>- Sales volume</td>
<td>600,000 units</td>
<td>400,000 units</td>
</tr>
<tr>
<td>- Target price</td>
<td>$160/Unit</td>
<td>$200/Unit</td>
</tr>
<tr>
<td>- Target cost</td>
<td>$136/Unit</td>
<td>$187.50/Unit</td>
</tr>
</tbody>
</table>

Let us assume that the schedule from the inception through market withdrawal is the following:

- Research and development: 3 quarters
- Design and manufacturing investment: 5 quarters
- Marketing: 11 quarters
- Distribution and customer-service: 10 quarters
- Production and sales window: 10 quarters.

The timing and magnitude of the cash flows is estimated by merging the project schedule with the program budget, the estimated production costs, and sales revenues. The level of detail should be relevant to the type of decision to be made. If a more precise analysis is required, the major cash flows presented above may be broken down into their sub-levels (production cost into direct and indirect costs for instance). The level of detail of cash flows should be coarse enough to be convenient to work with, yet it should contain enough information to permit effective decision making. A project cash flow table - whose columns are successive time periods, and whose rows are the different cash flow categories - can be used to compute the NPV of a product program. The rate of cash flows can be arranged in any way that best represents the team’s forecast of the cash flows. It is important to keep in mind that future cash inflows must be discounted by the
appropriate rate of return. Figure 6.5 presents the cash flow table of the example considered in this chapter.

The period cash flow for a given period is the sum of inflows and outflows during that same period. For instance, for the first quarter of year 3 (shaded area in figure 6.5), the period cash flow is:

<table>
<thead>
<tr>
<th>Item</th>
<th>Amount</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marketing cost</td>
<td>($727,000)</td>
</tr>
<tr>
<td>Distribution cost</td>
<td>($300,000)</td>
</tr>
<tr>
<td>Customer service cost</td>
<td>($400,000)</td>
</tr>
<tr>
<td>Production cost</td>
<td>($5,300,000)</td>
</tr>
<tr>
<td>Sales revenue</td>
<td>$9,600,000</td>
</tr>
<tr>
<td>Period cash flow</td>
<td>$2,873,000</td>
</tr>
</tbody>
</table>

The present value of this cash flow discounted at 10% per year (2.5% per quarter) back to the first quarter of year 1 (a total of 8 quarters) is: $2,873,000 / (1 + 0.025)^8 = $2,358,000.

The project Net Present Value (NPV) is simply the sum of the discounted cash flows for each period - that is $8,770,000. The expected NPV of the product program shows whether or not the program is profitable in the long run.

This model can support major investment decisions. Say for instance that company X were deciding between two production facilities requiring different manufacturing investments, and production costs (the first option being to reuse an existing facility, or to build a new one which would have lower production costs). They could run such a model for both scenarios, and choose the one with the best NPV. Other factors need to be taken into account, such as operating income, price per unit, cost per unit.
<table>
<thead>
<tr>
<th>Timeline</th>
<th>Year 1</th>
<th>Year 2</th>
<th>Year 3</th>
<th>Year 4</th>
<th>Year 5</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cash Flows</strong></td>
<td>Q1</td>
<td>Q2</td>
<td>Q3</td>
<td>Q4</td>
<td>Q1</td>
</tr>
<tr>
<td>Research and Development cost</td>
<td>($1,100)</td>
<td>($1,100)</td>
<td>($1,100)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Design and manufacturing investment cost</td>
<td>($2,000)</td>
<td>($2,000)</td>
<td>($2,000)</td>
<td>($2,000)</td>
<td>($2,000)</td>
</tr>
<tr>
<td>Marketing cost</td>
<td>($727)</td>
<td>($727)</td>
<td>($727)</td>
<td>($727)</td>
<td>($727)</td>
</tr>
<tr>
<td>Distribution cost</td>
<td>($300)</td>
<td>($300)</td>
<td>($300)</td>
<td>($300)</td>
<td>($300)</td>
</tr>
<tr>
<td>Customer-service cost</td>
<td>($400)</td>
<td>($400)</td>
<td>($400)</td>
<td>($400)</td>
<td>($400)</td>
</tr>
<tr>
<td>Production volume</td>
<td>60,000</td>
<td>60,000</td>
<td>60,000</td>
<td>60,000</td>
<td>60,000</td>
</tr>
<tr>
<td>Unit production cost</td>
<td>$88.8/u</td>
<td>$88.8/u</td>
<td>$88.8/u</td>
<td>$88.8/u</td>
<td>$88.8/u</td>
</tr>
<tr>
<td>Production cost</td>
<td>($5,300)</td>
<td>($5,300)</td>
<td>($5,300)</td>
<td>($5,300)</td>
<td>($5,300)</td>
</tr>
<tr>
<td>Sales volume</td>
<td>60,000</td>
<td>60,000</td>
<td>60,000</td>
<td>60,000</td>
<td>60,000</td>
</tr>
<tr>
<td>Sales revenue</td>
<td>$9,600</td>
<td>$9,600</td>
<td>$9,600</td>
<td>$9,600</td>
<td>$9,600</td>
</tr>
<tr>
<td>Period Cash Flows</td>
<td>($1,100)</td>
<td>($1,100)</td>
<td>($3,100)</td>
<td>($2,000)</td>
<td>($2,000)</td>
</tr>
<tr>
<td>Present Value Year 1, r=10%</td>
<td>($1,073)</td>
<td>($2,951)</td>
<td>($1,857)</td>
<td>($1,812)</td>
<td>($1,768)</td>
</tr>
<tr>
<td>Project NPV</td>
<td>$8,770</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 6.5 - Cash flow table example (S values in thousands). This table displays the expected net monetary gain or loss from a project by discounting all expected future cash flows and inflows to the present point in time. This analysis will help the product planners to better assess the long term profitability of a product program.
5- Sensitivity analysis for making better trade-offs

Sensitivity analysis is a “what-if” technique that examines how a result will change if the original predicted data are not achieved, or if an underlying assumption changes. It provides an immediate measure of the financial effect of differences between forecasts and actual outcomes. Therefore, it helps managers to focus on those decisions that may be very sensitive, and eases their mind about decisions that are not so sensitive.

In the context of manufacturing, the objective is to measure the change in the full product cost, the operating income, and the NPV of the program corresponding to changes in the factors included in the model. Internal factors are those over which the development team has a large degree of influence (market research expenses, development cost, development time, production cost, product performance and quality...). External factors are those that are not directly controlled by the team (product price, sales volume, competition, suppliers...).

Sensitivity analysis can take various forms. For instance, management may want to know how far cash inflows must fall to reach the point of indifference for the NPV of the project - \( \text{NPV} = 0 \), or by how much we need to cut investments to achieve our target cost, and how this would affect sales volumes.

They might be interested in determining how development cost variations affect the NPV of the project, the full product cost, or the operating income. By making incremental changes to development cost (research and development investment + design and manufacturing investment) while holding other factors constant, we can see the incremental impact on the project NPV, the full product cost, and the operating income (figure 6.6).¹

This type of analysis shows how critical reusability is from a cost reduction standpoint, and how reusability decisions can affect the profitability of a product through investment cost reduction.

We can also evaluate the impact of an increase in development time - which delays the start of the production ramp-up, and therefore product sales - on the NPV of the project. If we assume for instance that there is a fixed window for sales, an increase of the development time will clearly decrease the NPV of the project, other factors being

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¹ Note that computer spreadsheets enable managers to conduct systematic, efficient sensitivity analysis.
constant. Reusability can be once again a strategic enabler in development time reduction, and therefore a major source of profit.

<table>
<thead>
<tr>
<th>Change in Development Cost, %</th>
<th>Development Cost, $Thousands</th>
<th>Change in Product Cost, $</th>
<th>Change in Operating Inc., %</th>
<th>Change in NPV, $Thousands</th>
</tr>
</thead>
<tbody>
<tr>
<td>50</td>
<td>19950</td>
<td>8.1%</td>
<td>$147.1</td>
<td>-46.2%</td>
</tr>
<tr>
<td>20</td>
<td>15960</td>
<td>3.3%</td>
<td>$140.4</td>
<td>-18.5%</td>
</tr>
<tr>
<td>10</td>
<td>14630</td>
<td>1.6%</td>
<td>$138.2</td>
<td>-9.2%</td>
</tr>
<tr>
<td>base</td>
<td>13,300</td>
<td>0.0%</td>
<td>$136.0</td>
<td>0.0%</td>
</tr>
<tr>
<td>-10</td>
<td>11970</td>
<td>-1.6%</td>
<td>$133.8</td>
<td>9.2%</td>
</tr>
<tr>
<td>-20</td>
<td>10640</td>
<td>-3.3%</td>
<td>$131.6</td>
<td>18.5%</td>
</tr>
<tr>
<td>-50</td>
<td>6650</td>
<td>-8.1%</td>
<td>$124.9</td>
<td>46.2%</td>
</tr>
</tbody>
</table>

Production costs can also be decreased through reusability, making the best profit through the reuse of existing stable processes, and exploitation of the positioning in the experience curve. Sensitivity analysis can help to prove such advantages, and therefore provide managers with guidance in their decision making process.

However, interdependencies across cost pools make the sensitivity analysis sometimes more complex, as a change in a given cost pool might affect other cost pools (if the development cost increases by 10%, the sales volume will probably decrease as the cost of the product increases). In this case, several scenarios should be evaluated.
6- Dealing with uncertainty

Managers make predictions and decisions in an environment that is not deterministic. Rather, it is probabilistic, and surrounded with uncertainty. This section describes a systematic approach to risk assessment and dealing with uncertainty when making forecasts for sales volumes or market prices. It helps managers to deal with the uncertainty surrounding the outcome related to some investment decision - how would sales volumes be affected if the development cost is increased by 10%? Would a 5% increase of the investment ensure a better operating income?

Decision analysis structures the problem to bring out all the relevant choices, as well as all the possible outcomes that can be imagined. The means for doing this is the decision tree. It is a conceptual device for enumerating each of the possible decisions that can be made, and each of the possible outcomes that may occur according to each of the events that may arise. Thus, we have:

- An objective function which provides a basis for choosing the best alternative action.
  
  Maximize the net present value of the product program in the example.

- A set of possible decisions or actions, \( D_i \).
  
  \( D_1 = \) spend 10% more in product development for quality improvement.
  
  \( D_2 = \) spend 20% more in product development for quality improvement.

- A set of relevant events, \( E_j \), which should be mutually exclusive and collectively exhaustive.
  
  \( E_1 = \) Sales volume increase up to 650,000 units
  
  \( E_2 = \) Sales volume increase up to 750,000 units

- A set of probabilities, where a probability is the likelihood of occurrence of an event.
  
  If \( D_1 \) \( P(E_1) = 0.7 \) \( P(E_2) = 0.3 \)
  
  If \( D_2 \) \( P(E_1) = 0.4 \) \( P(E_2) = 0.6 \)

- A set of possible outcomes \( O_{ij} \) that result from having chosen \( D_i \) and being subject to \( E_j \).

---

1 The application of decision analysis to situations involving continuous probability distributions, and an infinite number of possible outcomes is essentially identical to the procedure just described. The only difference is that we must use integrals to evaluate the expected values.
Using and updating the table in figure 6.5, we see that the net present value of the product program considered, for each of the alternative decisions and relevant events, is:

\[
\begin{align*}
\text{NPV}(O_{11}) &= 13.6 \text{ million} \\
\text{NPV}(O_{12}) &= 25.7 \text{ million} \\
\text{NPV}(O_{21}) &= 12.4 \text{ million} \\
\text{NPV}(O_{22}) &= 24.4 \text{ million}
\end{align*}
\]

The optimal decision is the one with the best expected value for the outcomes. The expected value for each possible decision is easily calculated. It is simply the probabilistic average of the possible outcomes resulting from a given decision:\[ EV(D_i) = \sum_j P(E_j) O_{ij}. \] In the example, the expected net present value of each decision is computed as follows:

\[
\begin{align*}
EV(D_1) &= 0.7 \times (13.6) + 0.3 \times (25.7) = 17.2 \text{ million} \\
EV(D_2) &= 0.4 \times (12.4) + 0.6 \times (24.4) = 19.6 \text{ million}
\end{align*}
\]

To maximize the net present value of the product program, we need to invest 20% more in product development. The decision tree (figure 6.7) illustrates the decision analysis process.

Decision analysis helps management and decision makers:
- By structuring the problem to bring into focus the real range of risk and options.
- By defining an optimal choice when several alternatives are to be considered.

---

\footnote{In the case of an infinite number of events, and a continuous probability distribution for the events, the expected value of each decision is \( EV(D_i) = \int O_{ij} f(E_j) dE_j \), where \( f \) is the probability distribution of the events.}
<table>
<thead>
<tr>
<th>Decisions</th>
<th>Events</th>
<th>Outcome</th>
<th>Probability of events</th>
<th>Expected Net Present Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Sales = 650,000 units</td>
<td>$13.6 million</td>
<td>0.7</td>
<td>$9.5 million</td>
</tr>
<tr>
<td></td>
<td>Sales = 750,000 units</td>
<td>$25.7 million</td>
<td>0.3</td>
<td>$7.7 million</td>
</tr>
<tr>
<td></td>
<td>Sales = 650,000 units</td>
<td>$12.4 million</td>
<td>0.4</td>
<td>$5.0 million</td>
</tr>
<tr>
<td></td>
<td>Sales = 750,000 units</td>
<td>$24.4 million</td>
<td>0.6</td>
<td>$14.6 million</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$19.6 million</td>
</tr>
</tbody>
</table>

**Figure 6.7 - Decision-Tree**

D1 = Pay $17.2 million
D2 = Pay $19.6 million
Chapter VII - Strategic Reusability Planning and Management Process

Manufacturing companies face today unique challenges stemming from a more complex and volatile demand than ever. Henceforth, markets are driven by three major forces: rising product value, falling prices, and a growing demand for customized products. Understanding these constraints is the starting point in developing a successful product strategy which is the most important determinant of success for manufacturing companies.

Ideally we would like to provide each customer with exactly what he wants, with no time constraint at a competitive price. Disciplined reusability along with integrated technology, product and manufacturing strategies can help product planners to achieve such an ideal. Reusability, as described in the first chapter, is a strategic enabler in supporting breakthrough efforts for achieving affordable customer-perceived variety and freshness along with investment efficiency, design and manufacturing cost reduction, development time reduction and quality improvement. This chapter consists of an integration of the strategic reusability planning and management tools into a product strategy framework. We have tried in this section to address what we consider as being the key questions for the Product Development Team:

- How many new products?
- How new is each product?

1 Schnabel [1996] developed a step by step approach for implementing reusability in platform planning. In this chapter, we have built a more simplistic and analytical process for planning and implementing strategic reusability.
- How are the products grouped into platforms?

1- From strategic vision to platform concepts pre-definition

1.1- Defining the corporate strategic vision

Henry Ford envisioned a process that would put a car in every garage, Bill Gates saw better than anyone else that the explosion in microprocessors would create a vast array of opportunities for computer software. However, Ampex Corporation, which invented the video tape recorder in 1956, and that became a big success with broadcasting companies eventually, failed to identify the possibilities for the VTR in the consumer market. Hence, it lost the opportunity to be a key player in the multi-billion dollar consumer VCR market.

Step 1 - Define the strategic vision

Product strategy begins with a clear strategic vision which provides the context and direction for product strategy. It guides the product development team by telling the team members where the company is going, how to get there, and why the company will be successful. Any company with long term objectives must have a strategic vision. However, the issue is not to have a strategic vision, rather it is to define a strategic vision that will lead the company towards success.

Keeping in mind the purpose of the strategic vision helps in defining a successful path for any company. Its intent is five fold:

- Focus the efforts of those responsible for identifying new platform/product opportunities, and help them to select platform/product development options that are consistent with the company’s strengths. The business integration model introduced in chapter 2 will further enforce this purpose.

- Establish a framework for platform strategy. It helps in defining the nature, timing and competitive positioning of product platforms.

- Guide product development activities. A clear strategic vision helps align product development activities in a common direction, which helps product development teams share activities, design, facilities and tooling costs across similar projects.

- Provide general direction for core competency and technology development.
- Set high level expectations for customers, employees, and investors which will help the company achieve its vision.

Besides, a strategic vision must be simple to share, manage, and implement; sustainable for the foreseeable future; and innovative, identifying needs that have not yet emerged.

Responsibility for strategic vision rests clearly with the CEO or head of the business unit. In the case of a large diversified company, trying to develop a strategic vision at the corporate level might be ineffective. Rather, a specific vision should be developed for each business unit. McGrath [1995] has summarized the characteristics of the major types of strategic visions, ranging from Blind to Foresighted.

1.2- Analyzing the external environment

Step 2 - Build Porter’s Five Forces Model

One way to scan and organize information about the external environment of a company that shows us the potential attractiveness of its potential markets is the Five Forces Model developed by Michael Porter\(^1\), described in figure 7.1.

![Porter's Five Forces Model](image)

**Figure 7.1 - Porter's Five Forces Model**

The five forces shown in the figure help to explain the environment a company competes in, and the overall level of profitability it might expect from different market segments in a given industry. This also helps the company to assess how its current products meet customer needs in comparison with competitive products.

Porter’s model suggests that the expected level of profitability of a business, or market segment - at a lower scale - can be explained by five factors:

- Intensity of competition.
- Presence of substitute products.
- Buyer power.
- Power of suppliers
- Potential entrants.

An in-depth understanding of these factors will help the company to better define the set of core competencies it needs to develop to nurture future development projects, and the markets where it has the best opportunities given its internal capabilities.

1.3- Platform strategy - Defining the most promising platform concepts

1.3.1- Platform: Definition

A product platform is a collection of the common elements implemented across a range of products; it is the foundation for a number of related products. The nature of product platforms varies widely across industries and product applications. In the personal computer industry, a platform is the microprocessor combined with its operating system, such as the Apple Macintosh, and Intel/Windows platforms. In the automotive industry, a platform could be a set of underbody subassemblies (front structure, front floorpan, rear structure) that can be processed in a single underbody framing line.

Strategic reusability planning and management starts with platform concepts definition. There are four major reasons why a company should structure its products in product platforms:

- Provide distinct markets with customized products, while sharing technologies, engineering systems, and production processes to stay within business affordability, to reduce development time, and to improve quality; by focusing the company’s resources on the features that are the most important to the customers.
- Focus senior management on the most important decisions related to a product family instead of diluting attention across many products.
- Link a company’s strategic vision with its product development programs. The platform strategy is entitled to achieve the strategic vision, while
- Provide research and development engineers with specific directions for core competency and technology development.

1.3.2- Platform strategy - Platform concepts pre-definition

Step 3 - Define possible platform concepts

Based on the strategic vision and the analysis of the external environment, senior management must define the set of platforms which best reflects the strategic intent of the company, and its long term goals. They must select the most promising platform concepts. This initial phase of platform development defines the objectives and scope of all platforms that appear to be consistent with the company’s objectives. It includes an evaluation of the feasibility of each platform, and a selection of the best alternatives. A company may select several alternative platforms to address a general market segment, or a set of market segments, and postpone the decision to select the best one to the next phase (platform selection).

At this stage, senior management must have defined the most promising platform concepts, their underlying technology or defining elements1, their vector of differentiation2, their planned life-cycle, and how they will achieve a competitive sustainable advantage3 for the company. A platform plan displaying the expected life-cycle of all current platforms and the anticipated schedule for new alternative platforms should be built (figure 7.24).

It is very important to keep in mind that the number of platforms to be developed should not be defined at this stage. Rather, it should be done later after the assessment of the development resources required by each product platform, and the evaluation of the economic value of each platform.

1 In the automotive industry, a platform can be a set of underbody subassemblies that can be processed in a single underbody framing line, as stated previously. In the equipment design industry, it can be the frame.
2 Apple used “ease of use” as a vector of differentiation for its Macintosh Platform.
3 While the IBM PC was a very successful product platform, it did not give IBM a sustainable advantage - PC-clone manufacturers being able to acquire the platform underlying technology and reproduce it. As a result IBM lost market share.
Step 4 - Plan for platform commonization

Herein, the cycle planning team, or product strategy office must develop a particular effort to commonize product architectures, system designs, facilities, and tooling whenever possible within and across product-platforms - more specifically when planning for derivatives, or next generational platform. The benefits are multiple:

From an engineering design perspective:
- Minimal "clean sheet" designs
- Reduced time to market
- Proven product performance
- Proven subsystem compatibility (avoid packaging issues)...

From a manufacturing perspective:
- Reduced engineering and development costs
- Less need for prototypes and testing
- Reuse of assembly tooling
- Reduced tooling procurement costs (assembly tools, dies, fixtures)
- Optimal use of manufacturing facilities...

This first step in strategic reusability planning and management is entirely completed after senior management has nominated the platform champions, who will actually be responsible for the platform planning - define the set of product-lines and products to be developed - and the estimation of the platform profitability.

Figure 7.3 summarizes the first 4 steps of the strategic reusability planning and management process.

![Figure 7.3 - Strategic reusability planning and management: steps 1 to 4](image-url)
2- Platform planning

The platform teams should follow the process described below to define the set of product programs to be developed under their platform, and the inter-relationships among these product programs. It is of primary importance to have a high-level multifunctional team, with members representing marketing, product design, sales, and manufacturing functions.

2.1- Defining the strategic voice of the customer

Step 5 - Gather the strategic voice of the customer

The first step consists of gathering the voice of the customer. Most of the time, the company has products in the targeted market segments. Therefore, there does exist a pre-understanding of the customer profile. However, the platform team should conduct further market research to assess the new customer wants and their importance. This classification can be done through a KJ diagram [Shiba, Graham, and Walden 1993]. At this stage, agreement should be reached on which market segments are of interest to the company and on what basis, and the customer wants should be clearly attributed to the selected market segments.

Step 6 - Generate market segment map

Next, the platform team should generate a market segment map for the platform, that provides us with the importance of the different market segments - which can be based on sales volumes, or operating income per market segment- and the importance of the customer wants within each market segment. An overall importance for each customer want might then be computed as the product of the importance of the customer wants within the associated market segment and the market segment importance (an example is displayed in figure 7.4).
### Step 7 - Generate platform House of Quality

On this basis, and on the basis of the existing QFD information - Houses of Quality for previous product generations which were under the defined market segments, the platform team must build the Strategic, or Platform House of Quality. This defines the corporate expectations for the products to be developed under the considered platform, as well as their relative weight. The primary objective is to define customer needs, product expectations, and their linkages applicable to many market segments, far into the future. Thus, the master House of Quality will be the source for many product-specific Houses of Quality. One of the major benefits consists of an identification up-front of common features across product programs.

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Step 8 - Derive Houses of Quality for Core Products

Next the platform team must derive from the platform house of quality the core products Houses of Quality. A core product would be any product on the basis of which a family of products - differentiated in capacity, performance, features, packaging and quality - is built. The Intel 486 DX 25 MHz is an example of core product, from which an entire family of products was derived. A core product could also be defined as the starting product of a product-line\(^1\). As displayed in figure 7.5, the Houses of Quality of these core products could be directly derived from the master House of Quality by just deriving the appropriate set of rows and columns.

\[ \text{Figure 7.5 - Example of major product specific House of Quality} \]

\(^1\) McGrath [1995] defines a product-line as an integrated set of products with a similar, but somewhat different, purpose. Each product varies from others in the product-line by some characteristic such as capacity, performance, features...
2.2- Platform planning in the context of the corporate environment

**Step 9 - Generate the platform Business Integration Model**

At this point, the platform team must generate the business integration model for the platform considered based on the results of the previous step of the platform planning process, and a definition of the internal capabilities. The team must develop simultaneously the technology, product, and process strategies as explained in chapter 1. The BIM must display the entire set of potential products to be developed under the platform considered - including the derivatives of the core product of each product-line -, the plants supporting the production system, and the technology migration plan. This step includes an assessment of the corporate core competencies and internal capabilities which will be used as the basis on which the future technologies will be built.

The platform team must define the first set of high-level reusability degrees to be targeted between product-program generations, and across product-programs, based on the commonality existing between product expectations, and an analysis of the commonization and carryover opportunities - any vehicle system or production process which could be commonized or carried over, without altering the customer satisfaction, should be identified and targeted for reuse.

The platform team may build several BIMs corresponding to different market range alternatives, or different numbers of products per market segment. In any case, the platform BIMs have to be related to the total BIM which can be built at step 4 when planning for commonization across platforms.

**Step 10 - Prepare Aggregate Project Plan for each alternative**

In the previous section, the team defined the appropriate product mix, the sequencing of product-lines and derivatives, as well as the system and process high level reusability objectives for each product program.

The first step in building the Aggregate Project Plan consists of a definition of the types or classes of development projects covered by the BIM. Every firm has its own ranking of product-programs. At Ford Motor Company for instance, the Scaleability Process provides a consistent approach to “binning” programs based on program size and complexity, as well as degree of product change. Clausing [1994] has proposed a ranking of product programs from genesis to customized. This ranking of each product program
under one of these categories will help the platform team to grasp better the development resources required by each product program displayed in the BIM. The high level reusability targets set in the previous section will help to further detail the needs for each program.

Next, the platform team must define for each product program the critical resources\(^1\) and cycle time for its complete development. Competitive benchmarking might provide the platform planning team with guidance for determining the time and the people to be allocated to each product program. The team must also determine the capacity of the firm at the bottleneck of the product development cycle (which is usually human resources), and compute the utilization level for each period given the time frame of the product programs to be developed, as displayed in the BIM (figure 7.6). The utilization level should always be under 100\%. If it happened to be over 100\% during some period, the team must rethink the sequencing of its products, and revise the BIM for each product alternative until its plan falls within its internal capabilities.

<table>
<thead>
<tr>
<th>Development Resources Committed</th>
<th>Project Type</th>
<th>Projects' sequence</th>
</tr>
</thead>
<tbody>
<tr>
<td>(Measured in units at the bottleneck) (# of engineers)</td>
<td></td>
<td>1996</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
</tr>
<tr>
<td>30</td>
<td>Genesis W152</td>
<td></td>
</tr>
<tr>
<td>12</td>
<td>Associated W144</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Market-Segment Entry U86</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Variant U180</td>
<td></td>
</tr>
<tr>
<td>Number of product programs</td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>Critical Resource Utilization degree</td>
<td></td>
<td>65%</td>
</tr>
</tbody>
</table>

Total Number of design engineers 80
Average # of design engineers assigned 63%

Pre-program planning and analysis
Actual program (after approval)

**Figure 7.6 - Defining the programs' sequence and the bottleneck utilization level**

The BIM must be revised for each platform alternative and reflect the precedent change in the sequence of product programs.

\(1\) Most of the time, as stated by Wheelwright and Clark [1992], human resource is the bottleneck in product development; therefore, the timeframe of each product program is determined on the basis of the number of development engineers, product marketing people, and manufacturing people required to go from project conception through market introduction.
Developing an aggregated project plan might be a relatively simple and straightforward procedure; however carrying it out - moving from the first draft of the BIM to a robust, effective set of projects that matches and reinforces the product strategy - involves hard choices and discipline.

Figure 7.7 summarizes steps 5 to 10 of the strategic reusability planning and management process.

![Diagram showing steps 5 to 10 of the strategic reusability planning and management process.]

Figure 7.7 - Process steps 5 to 10
3- Advanced product planning - How new is each product?

This part introduces the tree analysis, and the product planning matrix introduced in chapters 3 and 4. This will help the platform team to define the exact reusability degrees at each product level, as well as the budget necessary to achieve a 100% customer satisfaction (product cost excluded at this point) for every product program. The following analysis is to be carried out separately for each platform alternative, and for each product to be developed under the same platform.

**Step 11 - Perform a Tree Analysis for each Core Product**

As stated previously a core product is defined as the first product in a product-line which is usually followed by a whole set of derivative products. The tree analysis will help the platform team to better assess the design and manufacturing change magnitudes required by each product expectation on the product functions, physical design, and production system as explained in chapter 3. We will use, to perform this task, the product expectations derived from the House of Quality for each Core Product, as defined in step 8.

The tree analysis should be completed by a clear definition of the reuse and innovation or change degrees - including the sources of the design and manufacturing solutions - to be targeted to 100% satisfy each product expectation. This will help the team to build the product planning matrix for each core product in the next step.

**Step 12 - Build a Product Planning Matrix for each Core Product**

The product planning matrix, as described in chapter 4, will help the platform team to define the minimum design, facilities and tooling change magnitude - that is the maximum reuse level - achieving a 100% customer satisfaction, for each Core Product Program. The budget necessary to achieve total customer satisfaction will then be defined for each core product program.

**Step 13 - Define the budget required by each product derivative, within every product-line**

The Product Planning Matrix of the core product of the product-line considered can be used to define the development cost (design plus facilities and tooling cost) of each derivative within the same product-line. A Product Planning Matrix may also be
derived for each derivative, the reference for design, facilities and tooling costs being those of the core product itself instead of those of a clean-sheet product.

This will give us the exact investment cost required by each product program.

**Step 14 - Estimate the product unit cost, and iterate back to step 12 until the target cost\(^1\) is achieved**

Based on sales volumes' forecasts, an estimate of marketing costs, an estimate of the production cost associated with the investment choices, and an estimate of overhead costs, the team can compute the product unit cost. If this cost is greater the target cost as determined by the marketing department, one more iteration is necessary back to step 12. We will have to enhance the reusability degree to meet the target cost. Once the target cost is achieved, we can go to the next step.

**Step 15 - Estimate the platform development cost**

After completion of these last three steps, the platform team will know the development cost of each product program, as well as the development cost of each platform alternative - the development cost of the platform being simply the sum of the development costs of each product-line within the platform; the cost of developing a product-line being the sum of the development costs of the core product and the derivatives within each product-line.

**Step 15' - Iterate back to step 12 until affordability is achieved**

That is to say if the estimate of the development resources actually required to build the platform - determined in the previous step - are within the company's capabilities (resources, and budgets), then the platform team should go for the next step. Otherwise, additional iterations might be necessary. The team will then have to go back to step 12, and enhance the reusability degrees of each product, or across products to reduce development expenditures, to stay within affordability.

Figure 7.8 summarizes steps 10 to 15 of the strategic reusability planning and management process.

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\(^1\) The target cost is defined as the market price minus the desired margin per product. However, we should keep in mind that the market price will depend on the degree of innovation.
10 - Prepare Aggregate Project Plan
Define cycle time and critical resources for each core product program

11 - Tree Analysis - Assess the change degree to be made to each core product

12 - Build a Product Planning Matrix PPM
for each core product, and for each of its derivatives

13 - Estimate the development cost of each product program

14 - Estimate product unit cost

Target Costs Achieved?

yes

no

15 - Estimate platform development cost

Stay within platform budget, and affordability targets?

yes

no

Figure 7.8 - Process steps 11 to 15
4- Platform concept selection

Step 16 - Economic Analysis - Defining the Operating Income, and the Net Present Value of each platform alternative - Cash flow analysis.

On the basis of an estimate of the sales volumes, the unit manufacturing cost, and marketing costs for each product-program, the platform team must assess the operating income, and the net present value of each product-program, as described in chapter 5. A complete cash flow table must be built for each product-program.

The operating income and the net present value of each platform alternative is then simply the sum of those of each product-program within the platform. Similarly, the cash flow for the platform for each period is computed as the sum of the cash flows of the product-programs under the same platform.

Step 17 - Select the best alternative for each platform concept, and the best platform concepts

The cycle planning team checks for consistency with the long term corporate goals, and selects the best alternative for each platform concept based on the economic analysis, and any other relevant piece of information (Return on Investment for instance).

Then, it selects the most promising platform concepts. The Pugh Concept Selection process can be used to complete this task.

Step 18 - Finalize the product development strategy

At this point, the team should finalize the BIM, the Aggregate Project Plan, and the Product Planning Matrices which will support the actual development of the final set of platforms.

Figure 7.9 summarizes steps 16 to 18 of the strategic reusability planning and management process.

Figure 7.10 is a road map for the strategic reusability planning and management process that enables the reader to quickly survey the entire process and thus obtain a strong perspective on the interconnections.
16 - Economic Analysis
The economic analysis must be carried out for each product within every platform. The Operating Income and NPV of the product programs under each platform should then be summed to assess the profitability of the platform alternative.

17 - Platform Pugh Concept Selection

18 - Finalize product development strategy

Figure 7.9 - Process steps 16 to 18
<table>
<thead>
<tr>
<th>Step #</th>
<th>Process steps</th>
<th>Rationale for each step</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Define the strategic vision</td>
<td>Where is the company going? How to get there? Why will it be successful?</td>
</tr>
<tr>
<td>2</td>
<td>Build Porter’s Five Forces Model</td>
<td>Scan and organize information about the external environment of the company, that shows the attractiveness of potential markets.</td>
</tr>
<tr>
<td>3</td>
<td>Define possible platform concepts</td>
<td>Define the set of platform concepts which best reflects the strategic intent of the company, and its long term goals.</td>
</tr>
<tr>
<td>4</td>
<td>Plan for platform commonization</td>
<td>Make effort to commonize product architectures, system designs, facilities and tooling, specifically when planning for derivatives, or next generational platforms.</td>
</tr>
<tr>
<td>5</td>
<td>Gather the strategic voice of the customer for each platform</td>
<td>Conduct market research to assess new customer wants and their importance.</td>
</tr>
<tr>
<td>6</td>
<td>Generate a Market Segment Map</td>
<td>Provide us with the importance of the different market segments, and the importance of customer wants within each market segment.</td>
</tr>
<tr>
<td>7</td>
<td>Generate platform House of Quality (HoQ)</td>
<td>Define the corporate expectations for the products to be developed under the considered platform, as well as their relative weight.</td>
</tr>
<tr>
<td>8</td>
<td>Derive Houses of Quality for Core Products</td>
<td>Derive from the platform HoQ the core products' HoQ.</td>
</tr>
<tr>
<td>9</td>
<td>Generate the platform Business Integration Model</td>
<td>Display core competency, technology, product and manufacturing strategies, as well as reusability plans for the platform concept studied here.</td>
</tr>
<tr>
<td>10</td>
<td>Prepare Aggregate Project Plan for each platform alternative</td>
<td>Define the timing of the product programs and the utilization level over time of the critical development resource - the bottleneck.</td>
</tr>
<tr>
<td>11</td>
<td>Perform a tree analysis for each core product</td>
<td>Assess the design and change magnitudes required by each product expectation on the product functions, the physical design, and the production system.</td>
</tr>
<tr>
<td>12</td>
<td>Build a Product Planning Matrix for each core product</td>
<td>Define the minimum design, facilities and tooling change magnitude achieving 100% customer satisfaction, and the corresponding budget.</td>
</tr>
<tr>
<td>13</td>
<td>Define the budget required by each product derivative</td>
<td>Assess the investment required for each product derivative within every product-line of the platform alternative considered.</td>
</tr>
<tr>
<td>14</td>
<td>Estimate the product unit cost, and iterate back to 12 until the target cost (market price - desired margin) is achieved</td>
<td>Enhance reusability degrees in the product planning matrix until the target cost is achieved.</td>
</tr>
<tr>
<td>15</td>
<td>Estimate the platform development cost</td>
<td>Provide the development team with an estimate of the resources required to actually develop the platform considered.</td>
</tr>
<tr>
<td>16</td>
<td>Iterate back to step 12 until affordability is achieved</td>
<td></td>
</tr>
<tr>
<td>17</td>
<td>Economic analysis - Cash flow analysis</td>
<td>Define the operating income, and the net present value of each platform.</td>
</tr>
<tr>
<td>18</td>
<td>Select best alternative for each platform concept and the best platform concepts</td>
<td>Based on the aggregated operating income, and net present value of each platform, the team makes its decision. Any other relevant information might be taken into account using the Pugh Concept Selection process.</td>
</tr>
<tr>
<td>19</td>
<td>Finalize the product development strategy</td>
<td>Analyze the BIM, the Aggregated Project Plan, and the Product Planning Matrix for the &quot;winning&quot; platform concepts.</td>
</tr>
</tbody>
</table>

Figure 7.10 - Strategic Reusability Planning and Management roadmap.
Chapter VIII - Conclusion

1- Summary of results

The purpose of this thesis was to create the strategic reusability planning and management process, to implement systematic and optimal reuse in product development. This process was built on the basis of a set of planning tools, some of which were developed in this thesis.

In chapter 3, we introduced an improved version of the business integration model, a strategic planning tool for supporting product, process, and technology planning, and enhancing business and engineering efficiency through reusability. The BIM will help companies to better use their resources, and better plan the proliferation of their products.

The following chapter presents one possible approach to defining the impact - in terms of design, facilities and tooling changes - of every new product expectation on the existing designs, and production facilities.

Next, we introduce the product planning matrix which will help product developers to achieve the best balance between reuse and innovation, combining existing assets with new assets to provide product variety and greater market presence relative to the development effort. This matrix will also help product developers to assess, before decisions are frozen, the consequences of their decisions on the probable achievement magnitude of the program’s product expectations; and therefore, adjust their choices to better meet customer and corporate-wants.
Chapter 6 introduces an approach to analyze the economic value of different product development alternatives; and therefore, to make the choices which maximizes the net profit for the company.

Finally, we introduce in chapter 7 the strategic reusability planning and management process which builds on the tools developed in this thesis, and those introduced in previous work on reusability. This process will help product planners to decide upon the number of platforms to be targeted for development, the number of products per platform, and the change magnitude to be made to each product; to maximize customer satisfaction, and the company's profit from both a short and a long term perspectives.

2- Further research

Throughout this thesis, we have encountered issues that were not fully resolved, and could form opportunities for further research.

In chapter 5, we built a model which will help product planners to achieve the best balance between investment cost reduction and customer satisfaction. This model would be best supported by a definition of the inter-dependencies existing between customer satisfaction and sales volumes on the one hand, investment costs and production costs on the other hand.

Besides, one of the most critical issues in implementing reusability was not discussed here: how to overcome the reuse barriers, and actually get people to adhere to the reusability plan? An empowered organization might be required to enforce reusability. This area is worthwhile to explore.

Another topic that might be of great interest to manufacturing companies is complexity reduction. Reusability is a strategic enabler for reducing complexity. However is it the only way to reduce complexity? How should complexity be measured: by the number of parts per product, or the number of models per part or process type? Maybe both.
Bibliography

Andrade, Ron and Don, Clausing (1995). “Strategic Integration of Products, Technologies and Core Competencies with Support of Planned Reusability”. Draft of an internal working paper of the Laboratory of Manufacturing and Productivity at MIT.


